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Water Quality in the Ganga River and Efficacy of Sewage Treatment Processes in Coliform Removal:

A Case for Adopting Tertiary Treatment

GRB EMP : Ganga River Basin Environment Management Plan

by

Indian Institutes of Technology

IIT Bombay | IIT Delhi | IIT Guwahati | IIT Kanpur | IIT Kharagpur | IIT Madras | IIT Roorkee

Preface

In exercise of the powers conferred by sub-sections (1) and (3) of Section 3 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government has constituted National Ganga River Basin Authority (NGRBA) as a planning, financing, monitoring and coordinating authority for strengthening the collective efforts of the Central and State Government for effective abatement of pollution and conservation of the river Ganga. One of the important functions of the NGRBA is to prepare and implement a Ganga River Basin: Environment Management Plan (GRB EMP).

A Consortium of 7 Indian Institute of Technology (IIT) has been given the responsibility of preparing Ganga River Basin: Environment Management Plan (GRB EMP) by the Ministry of Environment and Forests (MoEF), GOI, New Delhi. Memorandum of Agreement (MoA) has been signed between 7 IITs (Bombay, Delhi, Guwahati, Kanpur, Kharagpur, Madras and Roorkee) and MoEF for this purpose on July 6, 2010.

This report is one of the many reports prepared by IITs to describe the strategy, information, methodology, analysis and suggestions and recommendations in developing Ganga River Basin: Environment Management Plan (GRB EMP). The overall Frame Work for documentation of GRBMP and Indexing of Reports is presented on the inside cover page.

There are two aspects to the development of GRB EMP. Dedicated people spent hours discussing concerns, issues and potential solutions to problems. This dedication leads to the preparation of reports that hope to articulate the outcome of the dialog in a way that is useful. Many people contributed to the preparation of this report directly or indirectly. This report is therefore truly a collective effort that reflects the cooperation of many, particularly those who are members of the IIT Team. A list of persons who have contributed directly and names of those who have taken lead in preparing this report is given on the reverse side.

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Contents

1. Introduction

The Ganga River, the longest river system in India, drains a basin of extraordinary variation in altitude, climate, land use, cropping pattern and socio-economic condition. The Ganga River basin, which is the largest river basin in India, houses about 40% population of the country. The river provides a wide range of commodities and services that are pivotal in supporting the livelihoods for a large number of people in the basin. Due to the prevailing semi-arid climate and highly erratic monsoonal rains in the basin, the river flow heavily fluctuates and has subsequently been regulated by various human interventions like dams and barrages for domestic water supply and irrigation. During the course of her journey from Gangotri to Ganga Sagar, municipal wastewaters from large urban centers, trade effluents from industries and pollutants from several other point and diffused sources are released into the river and thereby severely degrading her water quality. Over the last few decades, increased attention has been given by the Government of India (GoI) in the form of River Action Plan (RAP), namely Ganga Action Plan (GAP) to maintain the river water quality through abatement of pollution. Unfortunately, the implementation of GAP has more or less failed to get the desired result as the GAP monotonously focused on the reduction of point sources of organic pollution rather than microbial pollution and diffused or non-point sources of pollution. Moreover, the majority of secondary-level sewage treatment technologies adopted under GAP are highly incapable in removing microbial pollution. In regard to the microbial pollution in the river, attention has been paid to blindly importing and fixing the ‘bathing class’ standards from the developed countries in terms of coliforms only as a measure of fecal pollution. Currently, countries worldwide adopt ‘zero discharge’ or ‘no return flow’ concept to maintain river water quality by recycling and reusing the treated wastewater/effluent for non-potable, non-human contact uses. In these contexts, this report is primarily aimed at analyzing water quality trend of the entire course of the Ganga River for the last 25 years (since the implementation of GAP) in order to substantiate and propagate the adoption of tertiary-level treatment of wastewater in the Ganga River Basin.

Section 2 of the report presents water quality trends in terms of organic pollution (dissolved oxygen, biochemical oxygen demand) and microbial pollution (total and fecal coliform) over 70 locations in entire course of the Ganga River for the past 25 years and inferences from the water quality analysis. Section 3 of the report discusses comparative monsoon characteristics and river flows of the western rivers *vis-à-vis* Indian rivers, the Ganga River in particular. The microbial pollution removal potential of the secondary-level sewage treatment technologies has been critically reviewed and discussed in Section 4 of the report. The last section of the report (Section 5) analyzes and evaluates the performance of commonly adopted disinfection technologies in terms of microbial pollution removal and other key parameters including hazardous by-product formation, required footprint of the technology, treatment cost and life-cycle cost.

This report is primarily based on the collation of secondary data, available mainly in the form of reports, papers and articles on flow and water quality of the Ganga River, microbial pollution removal potential of secondary-level sewage treatment technologies, and the performance of commonly adopted treatment technologies for disinfection of secondary sewage effluent.

2. Water Quality Trends of the Ganga River

Conventionally surface water quality and pollution, both organic and microbial, are assessed through analysis of various parameters like dissolved oxygen (DO), biochemical oxygen demand (BOD_5), total and fecal coliform (TC and FC), and hence historical data of the past 25 years (1986-2010) on these parameters were collated. Water quality data of the selected parameters over 70 locations in entire course of the Ganga River has been gathered by various investigators/organizations at the behest of the National River Conservation Directorate (NRCD). These data for the past 25 years (1986-2010) have been collated from the NRCD and used for analysis to depict the water quality trends. Simple average of twelve months in a year is considered as annual average while the simple average of dry months (November through June) and wet months (July to October) in a year are taken as average for dry and wet seasons, respectively for a particular location. Trends in various water quality parameters are observed by grouping five year data and observing spatial variation in five-year averages during dry and wet seasons as well as over twelve months. The results are presented in Figures 1 to 4. Statistically, the confidence level (as percentage) of observations conforming to the designated best-use classification (Classes A, B and C considered only) of inland surface water, as specified by the CPCB, have also been computed and presented in Annexure I. Following observations and inferences on the trends in water quality parameters of the Ganga River can be made from the information presented in Figures 1 to 4 and the confidence level values presented in Annexure I:

- The averages of DO (Figure 1) and BOD_5 (Figure 2) during dry as well as wet seasons and annually over the years at all locations in the entire course of the Ganga River appear to have remained fairly constant. The DO values over the years, in general, are on the higher side and conform to the designated best-use classification. Organic content as measured by BOD_5, however, does not conform to the limit specified for the designated best-use classification at some of the locations as revealed by the very low confidence level values (Annexure I). The DO values during wet season are lower as compared to dry season although the level of organic pollution (BOD_5) remains fairly constant during both the seasons at most of the locations. The level of organic pollution (BOD_5) is substantially high in the Fatehgarh-Tarighat stretch during dry as well as wet seasons over the years despite the fact that the DO level is on the higher side. Higher level of organic pollution in the Fatehgarh-Tarighat stretch is due to the fact that the stretch is subjected to severe anthropogenic pollution in the form of discharge of partially-treated or untreated sewage and industrial effluents.

- Coliform levels, both total and fecal (Figures 3-4) during dry as well as wet seasons are substantially higher and do not conform to the designated best-use classification at most places (Annexure I) barring few upstream locations. The coliform levels during wet season are significantly higher as compared to dry season at most of the locations. The coliform levels in the river are observed to be decreased during 1991-1995 as compared to 1986-1990. Since then, however, the coliform levels are on the rise and substantially increased from 1996 through 2010 at all locations in the entire course of the Ganga River.

- No significant change is observed in most of the water quality parameters except for total and fecal coliforms during dry as well as wet seasons and annually over the years at all locations in the entire course of the Ganga River. Hence, the river is subjected to severely increasing microbial pollution despite insignificantly higher organic pollution.

- Based on the aforementioned observations it may be stated that trends in water quality parameters and level of organic and microbial pollution do not support the postulate that interception, diversion and treatment schemes under GAP and other programmes lead to improvements in river water quality, particularly the most targeted parameters, namely DO, BOD_5 and coliform. On the contrary, the microbial pollution in the river is observed to be ever increasing since 1996. Implementation of intervention schemes and regulatory mechanisms under RAP has only changed the pattern of discharge of wastewaters generated through domestic and industrial activity rather than the improvement in river water quality, especially microbial pollution. Therefore, it makes sense to adopt tertiary level treatment of wastewater in India, the Ganga River basin in particular considering the level of microbial pollution in the Ganga River.

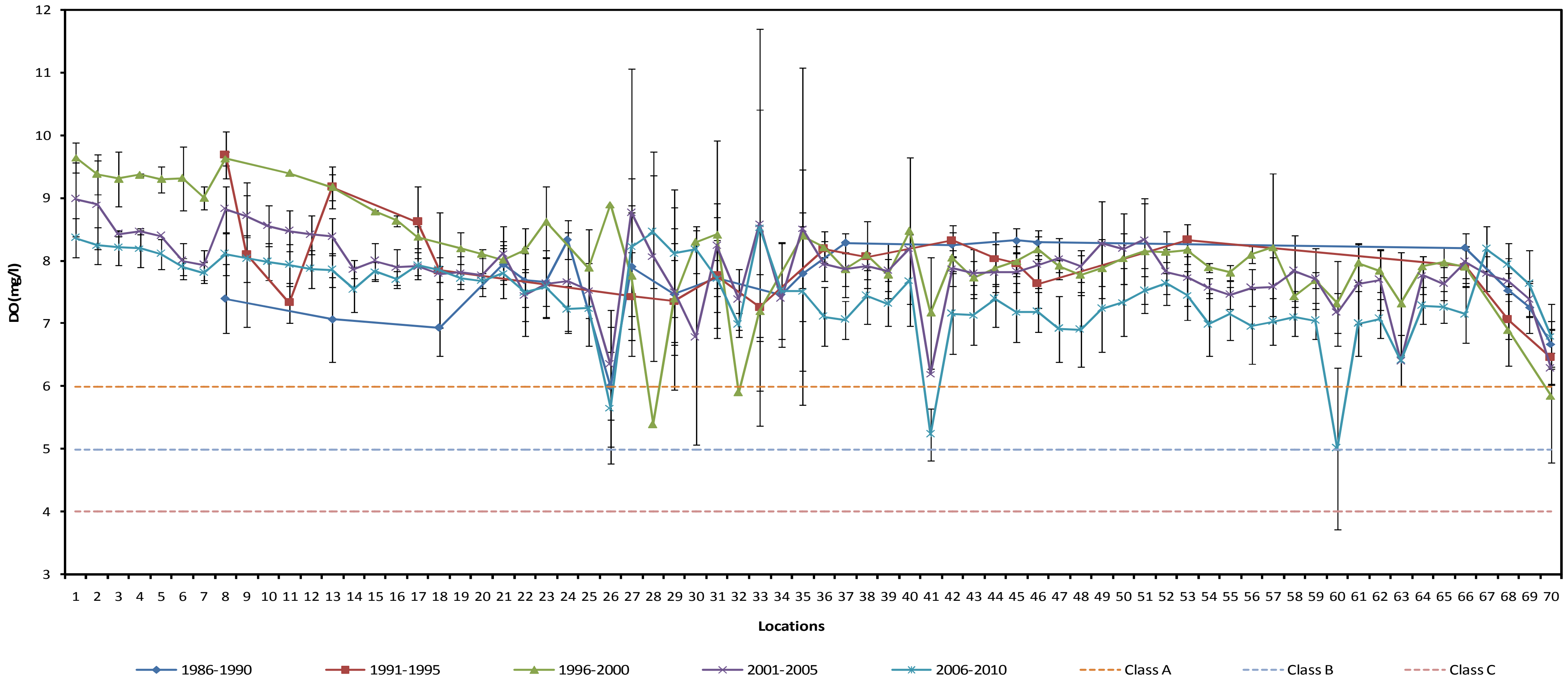

Figure 1(a): Variation in 5-year Average DO at Various Locations along the Ganga River during Dry Season

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, Pakka Ghat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
4	Devprayag u/s (Alaknanda)	18	Garhmukteshwar d/s	32	Dashashawmedh Ghat	46	Patna d/s	60	D/s Champanala
5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
6	Ranipur u/s (Ganga)	20	Anoopshahr d/s (Ganga)	34	Near Malviya Bridge	48	Fatuha d/s	62	Kahalgaon d/s
7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (Ujahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

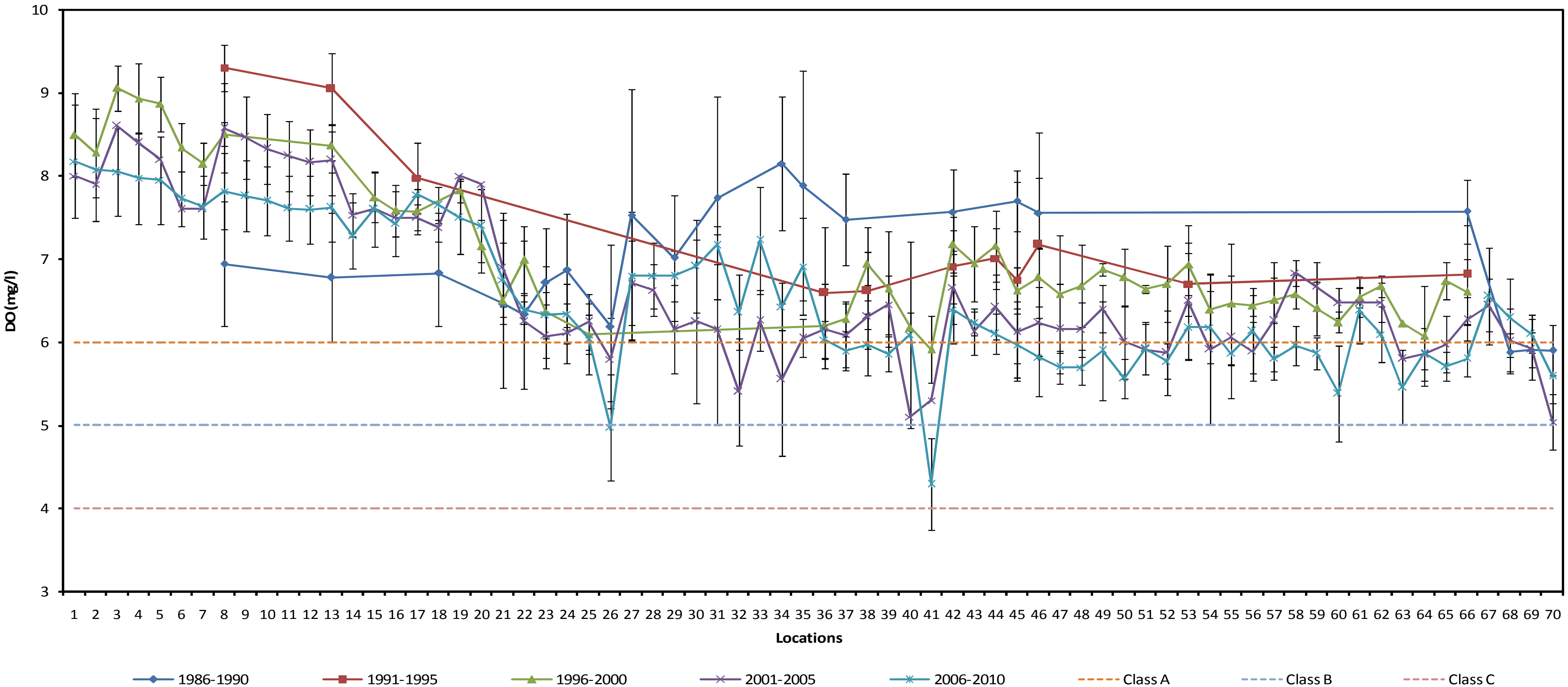

Figure 1(b): Variation in 5-year Average DO at Various Locations along the Ganga River during Wet Season

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, Pakka Ghat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
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5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
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8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (Ujahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

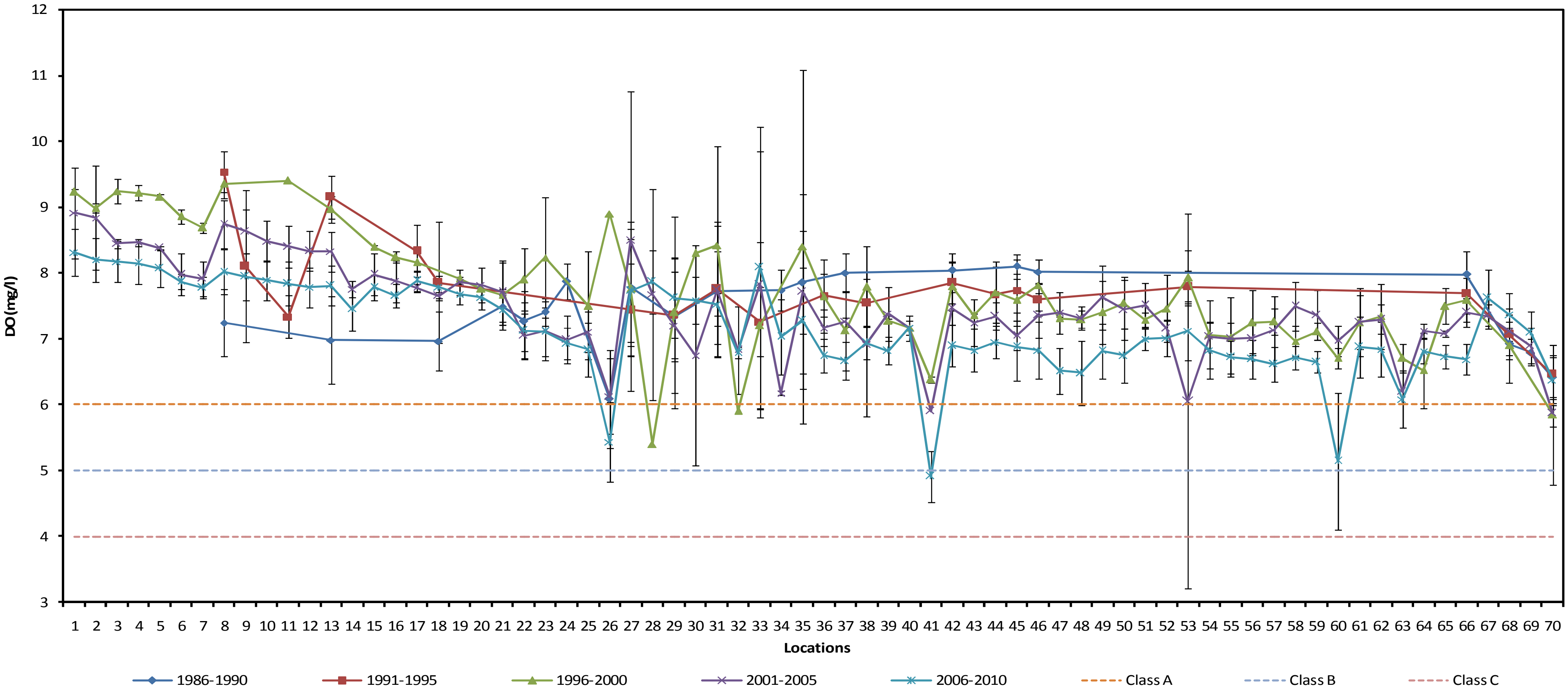

Figure 1(c): Variation in 5-year Average DO at Various Locations along the Ganga River

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, Pakka Ghat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
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7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
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9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (Ujahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

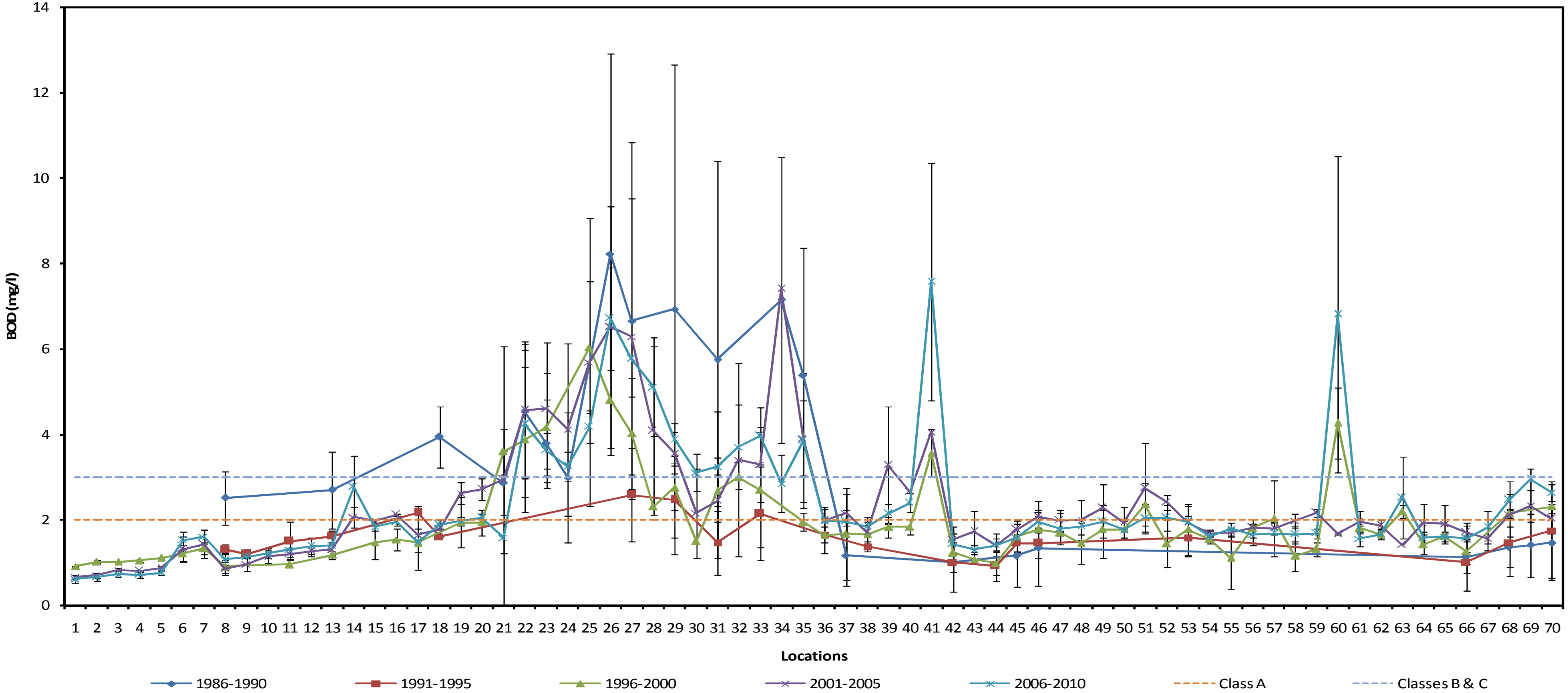

Figure 2(a): Variation in 5-year Average BOD_5 at Various Locations along the Ganga River during Dry Season

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, Pakka Ghat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
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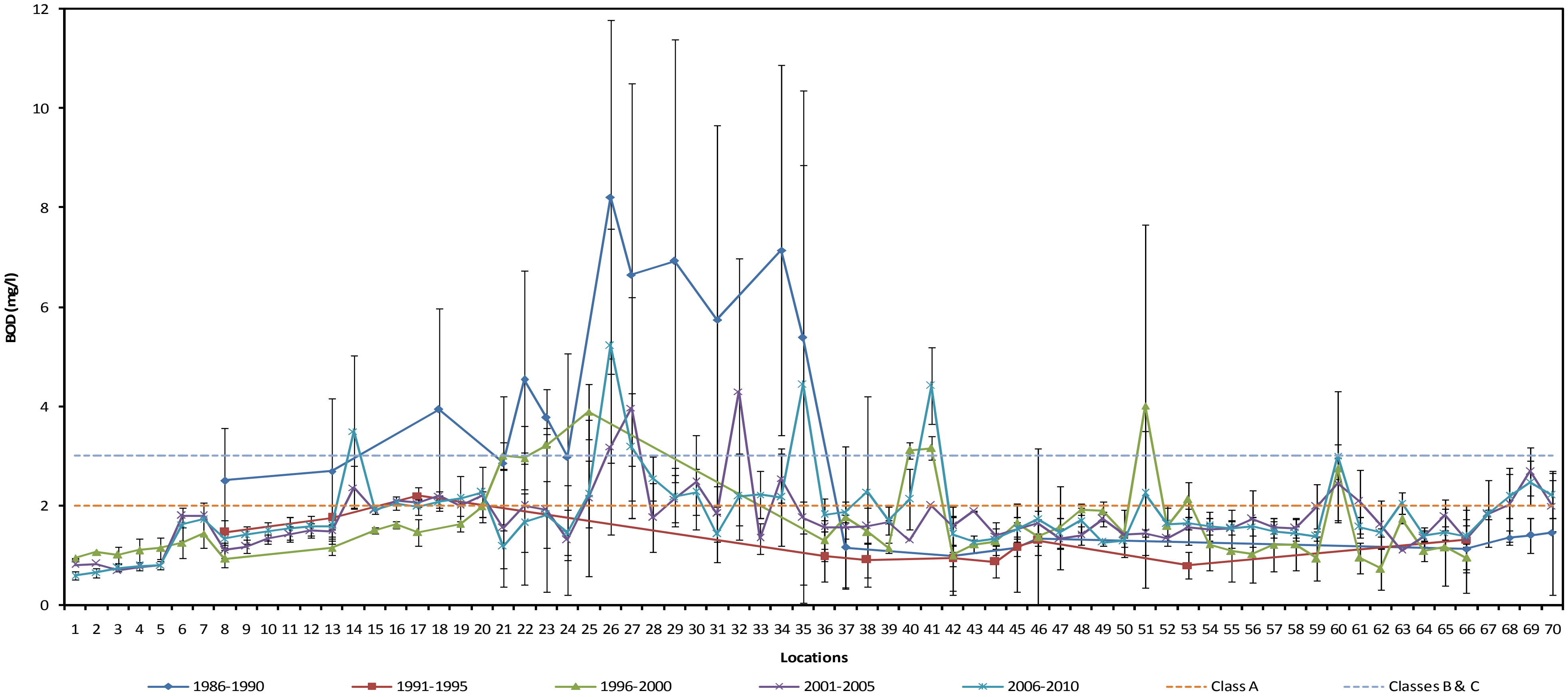

Figure 2(b): Variation in 5-year Average BOD_5 at Various Locations along the Ganga River during Wet Season

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
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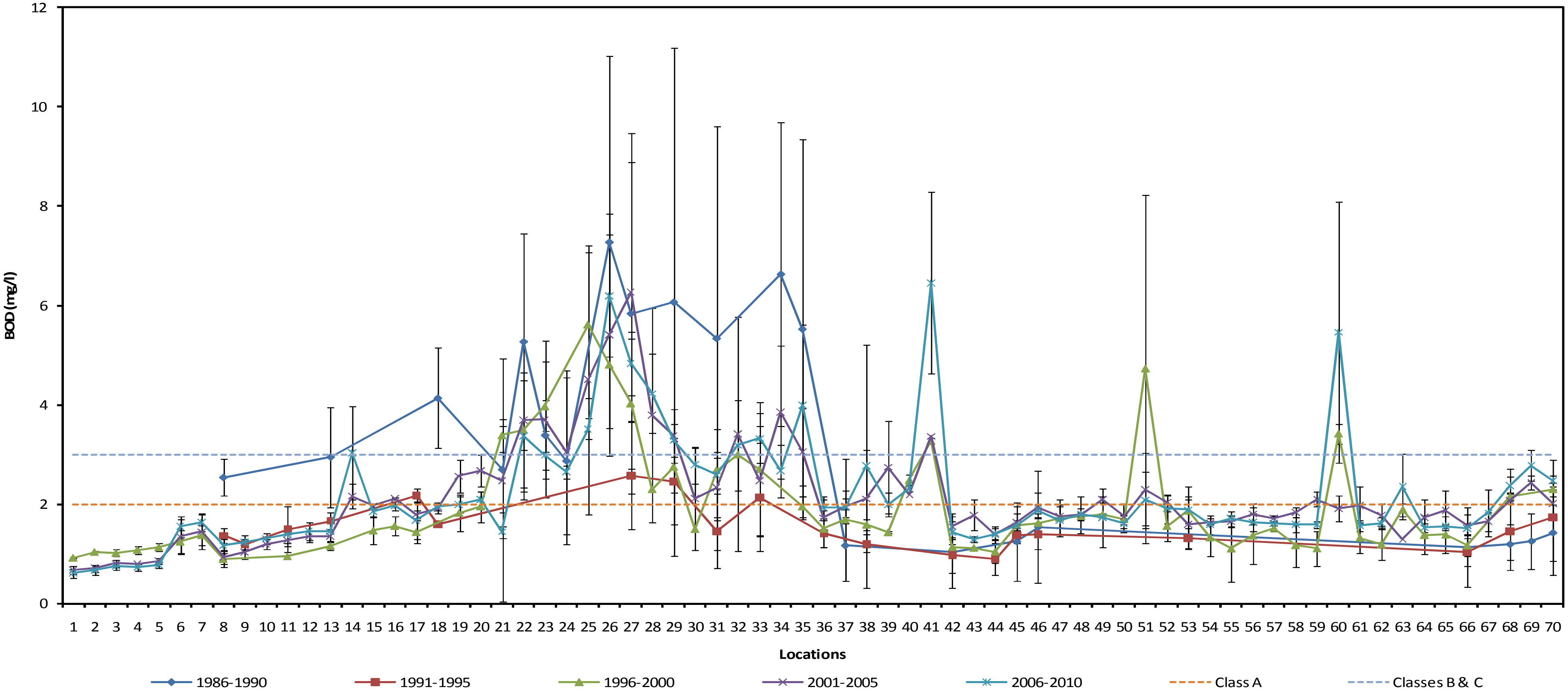

Figure 2(c): Variation in 5-year Average BOD_5 at Various Locations along the Ganga River

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, Pakka Ghat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
4	Devprayag u/s (Alaknanda)	18	Garhmukteshwar d/s	32	Dashashawmedh Ghat	46	Patna d/s	60	D/s Champanala
5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
6	Ranipur u/s (Ganga)	20	Anoopshahr d/s (Ganga)	34	Near Malviya Bridge	48	Fatuha d/s	62	Kahalgaon d/s
7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (Ujahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

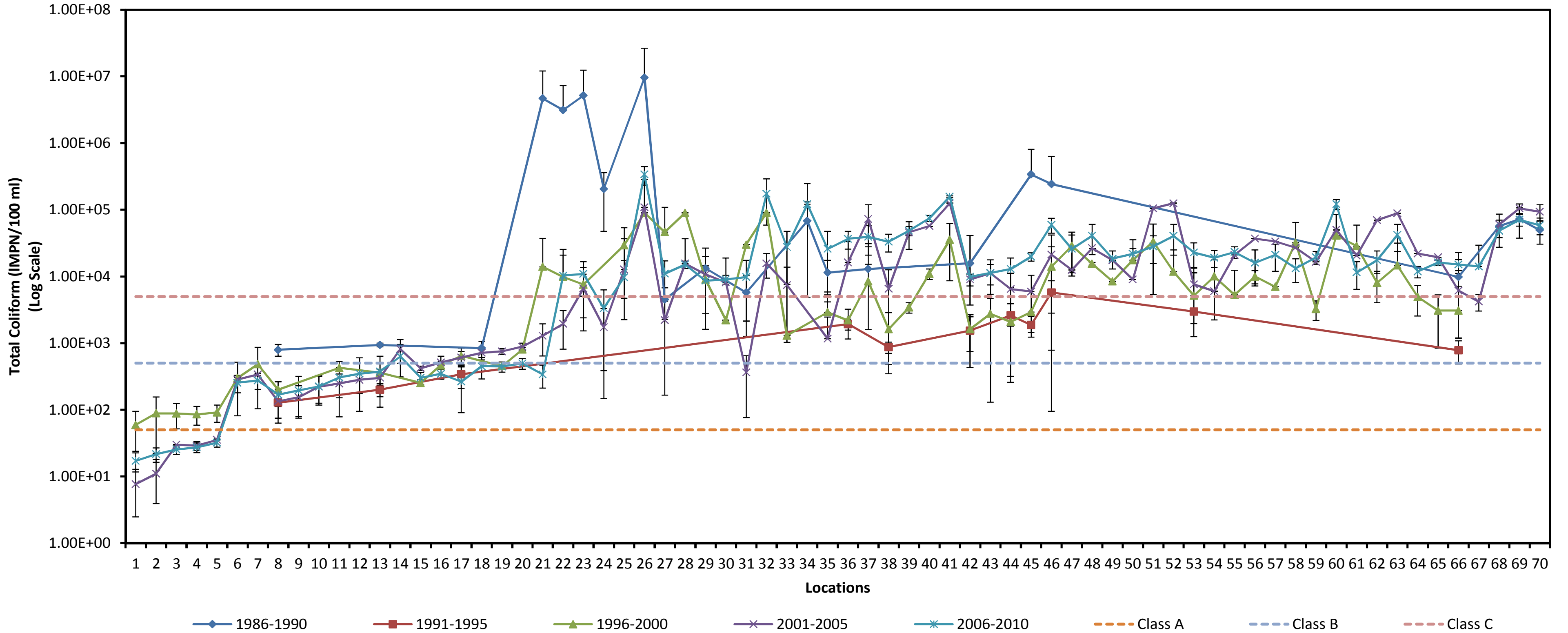

Figure 3(a): Variation in 5-year Average Total Coliform at Various Locations along the Ganga River during Dry Season

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, Pakka Ghat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
4	Devprayag u/s (Alaknanda)	18	Garhmukteshwar d/s	32	Dashashawmedh Ghat	46	Patna d/s	60	D/s Champanala
5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
6	Ranipur u/s (Ganga)	20	Anoopshahr d/s (Ganga)	34	Near Malviya Bridge	48	Fatuha d/s	62	Kahalgaon d/s
7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (Ujahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

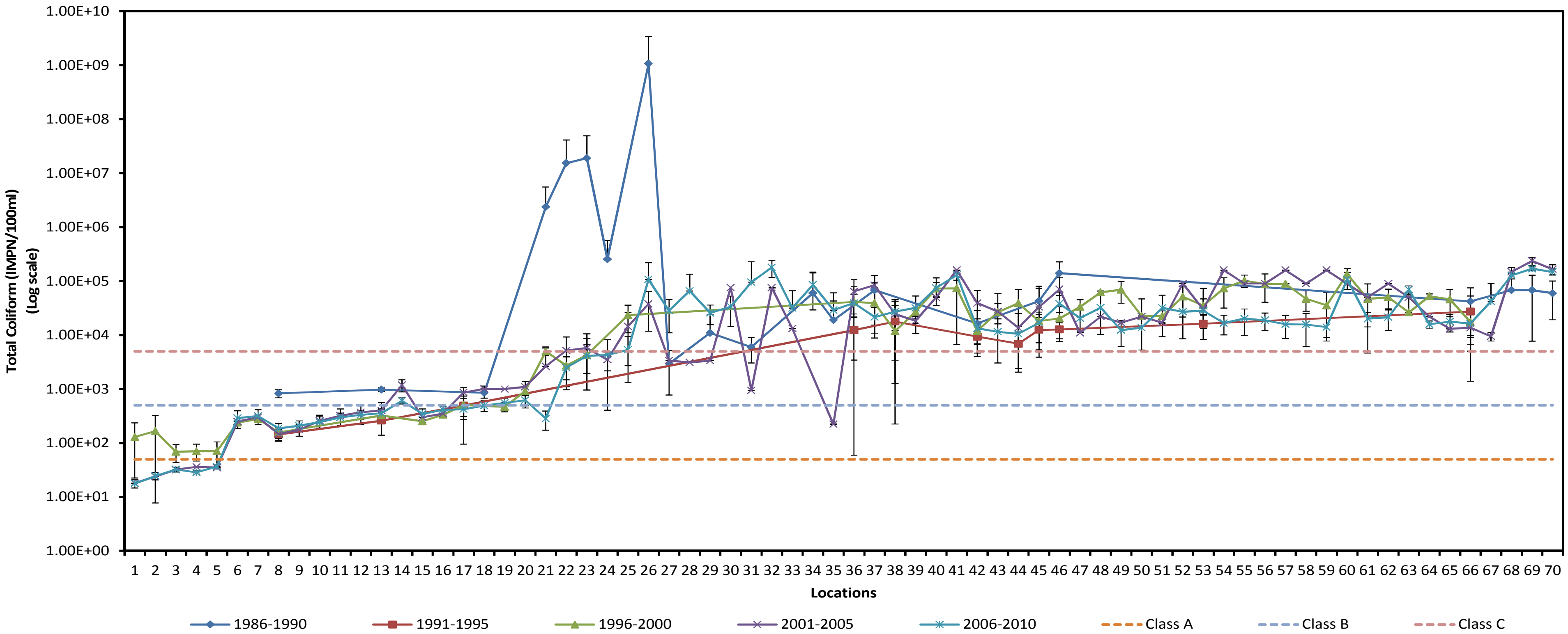

Figure 3(b): Variation in 5-year Average Total Coliform at Various Locations along the Ganga River during Wet Season

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, Pakka Ghat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
4	Devprayag u/s (Alaknanda)	18	Garhmukteshwar d/s	32	Dashashawmedh Ghat	46	Patna d/s	60	D/s Champanala
5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
6	Ranipur u/s (Ganga)	20	Anoopshahr d/s (Ganga)	34	Near Malviya Bridge	48	Fatuha d/s	62	Kahalgaon d/s
7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (Ujahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

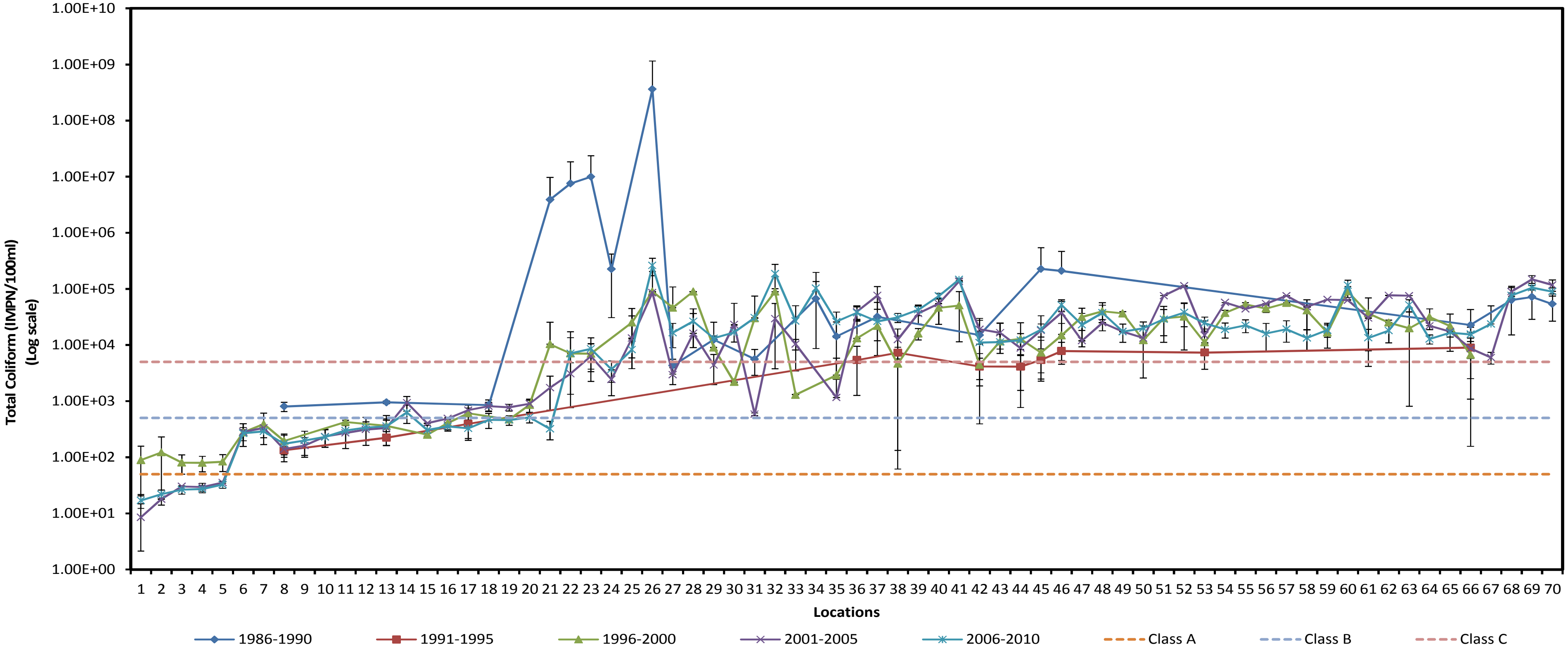

Figure 3(c): Variation in 5-year Average Total Coliform at Various Locations along the Ganga River

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, Pakka Ghat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
4	Devprayag u/s (Alaknanda)	18	Garhmukteshwar d/s	32	Dashashawmedh Ghat	46	Patna d/s	60	D/s Champanala
5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
6	Ranipur u/s (Ganga)	20	Anoopshahr d/s (Ganga)	34	Near Malviya Bridge	48	Fatuha d/s	62	Kahalgaon d/s
7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (Ujahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

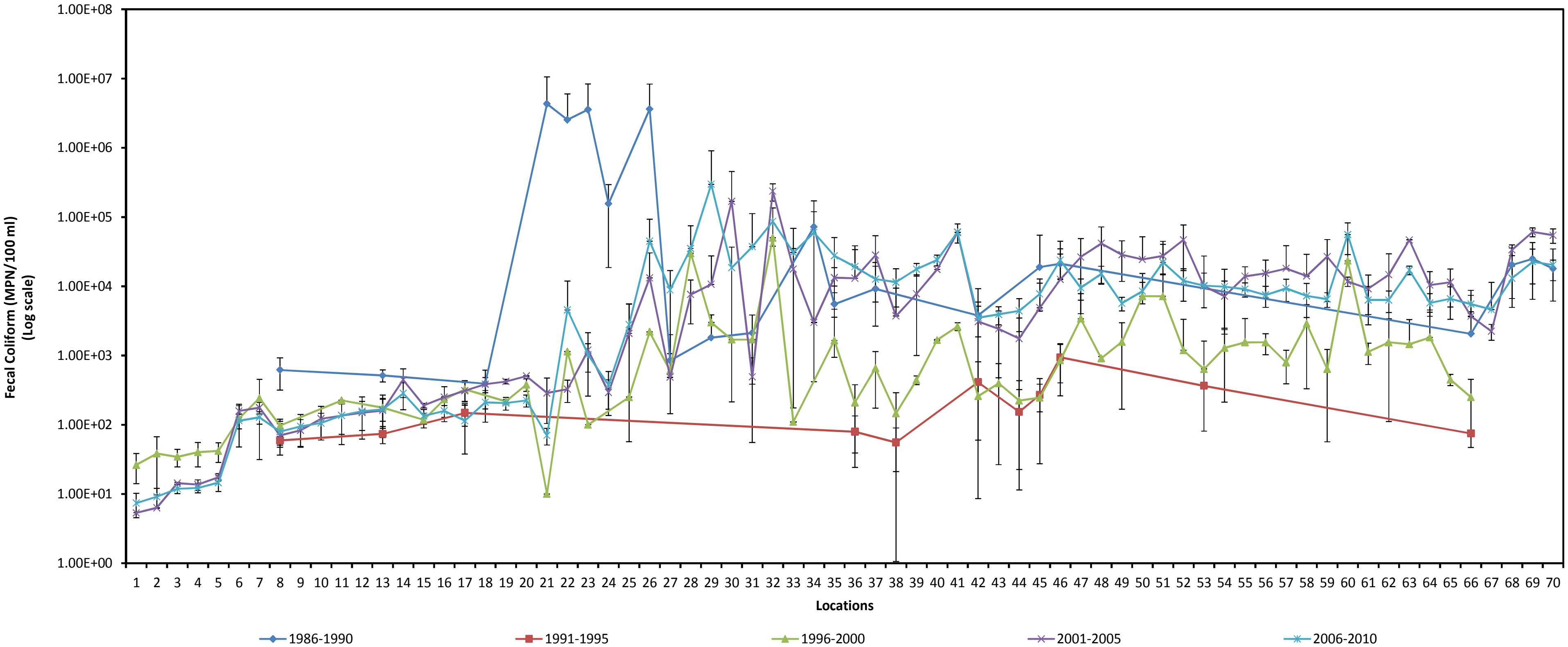

Figure 4(a): Variation in 5-year Average Fecal Coliform at Various Locations along the Ganga River during Dry Season

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, Pakka Ghat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
3	Devprayag u/s (Bhagirathi)	17	Garhmukteshwar u/s	31	Varanasi u/s	45	Patna u/s	59	Bhagalpur d/s
4	Devprayag u/s (Alaknanda)	18	Garhmukteshwar d/s	32	Dashashawmedh Ghat	46	Patna d/s	60	D/s Champanala
5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
6	Ranipur u/s (Ganga)	20	Anoopshahr d/s (Ganga)	34	Near Malviya Bridge	48	Fatuha d/s	62	Kahalgaon d/s
7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
11	Har-ki-Paudi	25	Kanpur d/s (Shuklaganj)	39	Chapra d/s (Chapra)	53	D/s Bata - McDowell	67	Berhampore (Middle)
12	Lalta Rao	26	Kanpur d/s (Jane Village)	40	Arrah u/s (River Gangi)	54	Munger u/s	68	Palta (Middle)
13	Dam Kothi	27	Allahbad u/s (Ujahni, Fatehpur)	41	Arrah d/s (River Gangi)	55	Munger d/s	69	Dakshineswar (Middle)
14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

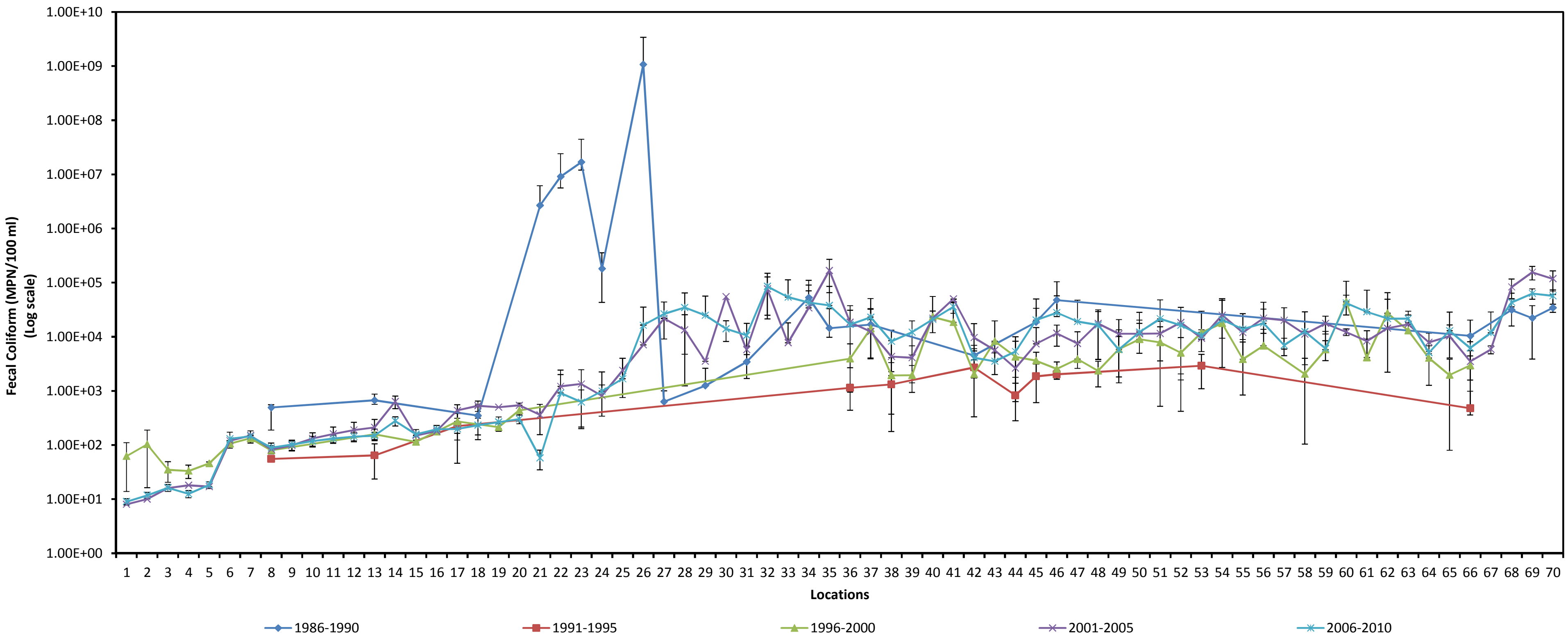

Figure 4(b): Variation in 5-year Average Fecal Coliform at Various Locations along the Ganga River during Wet Season

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
2	Uttarkashi d/s (Bhagirathi)	16	Bijnore d/s (Ganga)	30	Vindhyachal, Pakka Ghat	44	Hajipur d/s (River Gandak)	58	Bhagalpur u/s
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4	Devprayag u/s (Alaknanda)	18	Garhmukteshwar d/s	32	Dashashawmedh Ghat	46	Patna d/s	60	D/s Champanala
5	Devprayag d/s (Ganga)	19	Anoopshahr u/s (Ganga)	33	D/s at Kaithy	47	Fatuha u/s	61	Kahalgaon u/s
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7	Ranipur d/s (Ganga)	21	Fatehgarh u/s	35	Tarighat	49	Barh u/s	63	D/s NTPC Drain
8	Rishikesh u/s	22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	36	Buxar u/s	50	Barh d/s	64	Sahebganj u/s
9	Rishikesh d/s	23	Kannauj d/s (a/c with Kali)	37	Buxar d/s	51	Mokama u/s	65	Sahebganj d/s
10	Haridwar u/s	24	Kanpur u/s (Bithoor)	38	Chapra u/s (Ghaghra)	52	Mokama d/s	66	Rajmahal d/s
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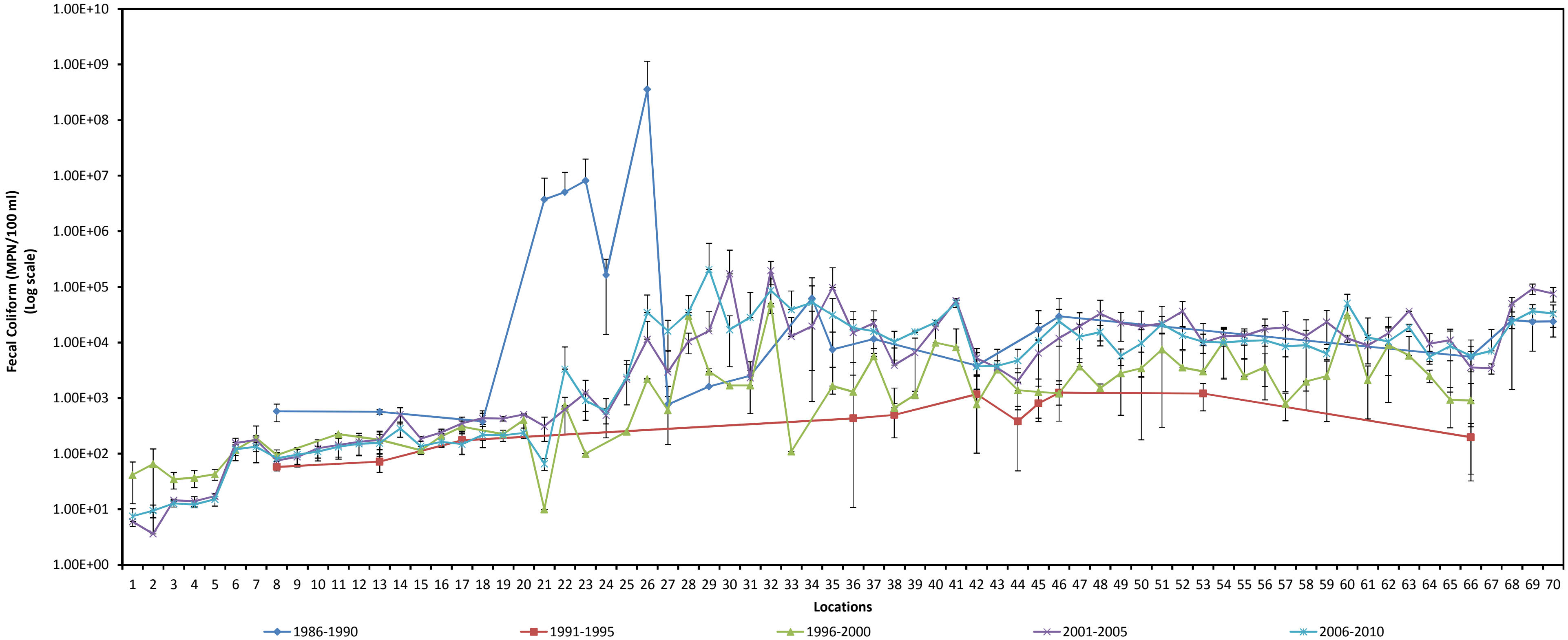

Figure 4(c): Variation in 5-year verage Fecal Coliform at Various Locations along the Ganga River

1	Uttarkashi u/s (Bhagirathi)	15	Bijnore u/s (Ganga)	29	D/s Deehaghat	43	Hajipur u/s (River Gandak)	57	Sultanganj d/s
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14	Mishrpur	28	Bathing Ghats at Sangam	42	Koliwar (River Sone)	56	Sultanganj u/s	70	Uluberia (Middle)

3. Monsoon and River Flow Characteristics – Western Rivers *vis-à-vis* Indian Rivers

In order to further substantiate the argument for adapting tertiary-level of wastewater treatment, a comparative assessment of monsoon and river flow characteristics of western rivers *vis-à-vis* Indian rivers would be useful. It is important to note that the rivers in western countries are either snow-fed and/or rain-fed, whereas the Indian rivers are mainly rain-fed. Further insights on Indian sub-tropical climatic conditions suggest that much of the rainfall occurs during monsoon season (June to September) and a dramatic increase in river flow is observed. River flow declines sharply during post-monsoon season (October to November). With occasional bursts of winter rainfall due to retreat of the south-west monsoon, the river flow continues to decline during both winter (December to February) and summer (March to May) seasons. Figure 5 presents the monthly rainfall and river flow plots for some of the western as well as Indian rivers in a typical year. It is evident from Figure 5 that the western rivers are snow-fed and/or rain fed for at least 120 days in a year whereas, flows in Indian rivers last merely for 30-60 days during monsoon only.

The western countries generally treat wastewater up to tertiary level despite having adequate river flows for dilution of the discharged effluent. The Indian paradigm adopts treatment of wastewater up to secondary level only and promotes disposal of secondarily-treated wastewater effluent into rivers despite having lean season of river flows of about 10 months in a year. This results in further degradation of the water quality of the river, especially in terms of fecal contamination. Therefore, the case for adopting tertiary level treatment of wastewater in India, the Ganga River basin in particular, finds further substantiation due to the prevailing climatic and monsoon characteristics and lean river flows during most of the time in a year.

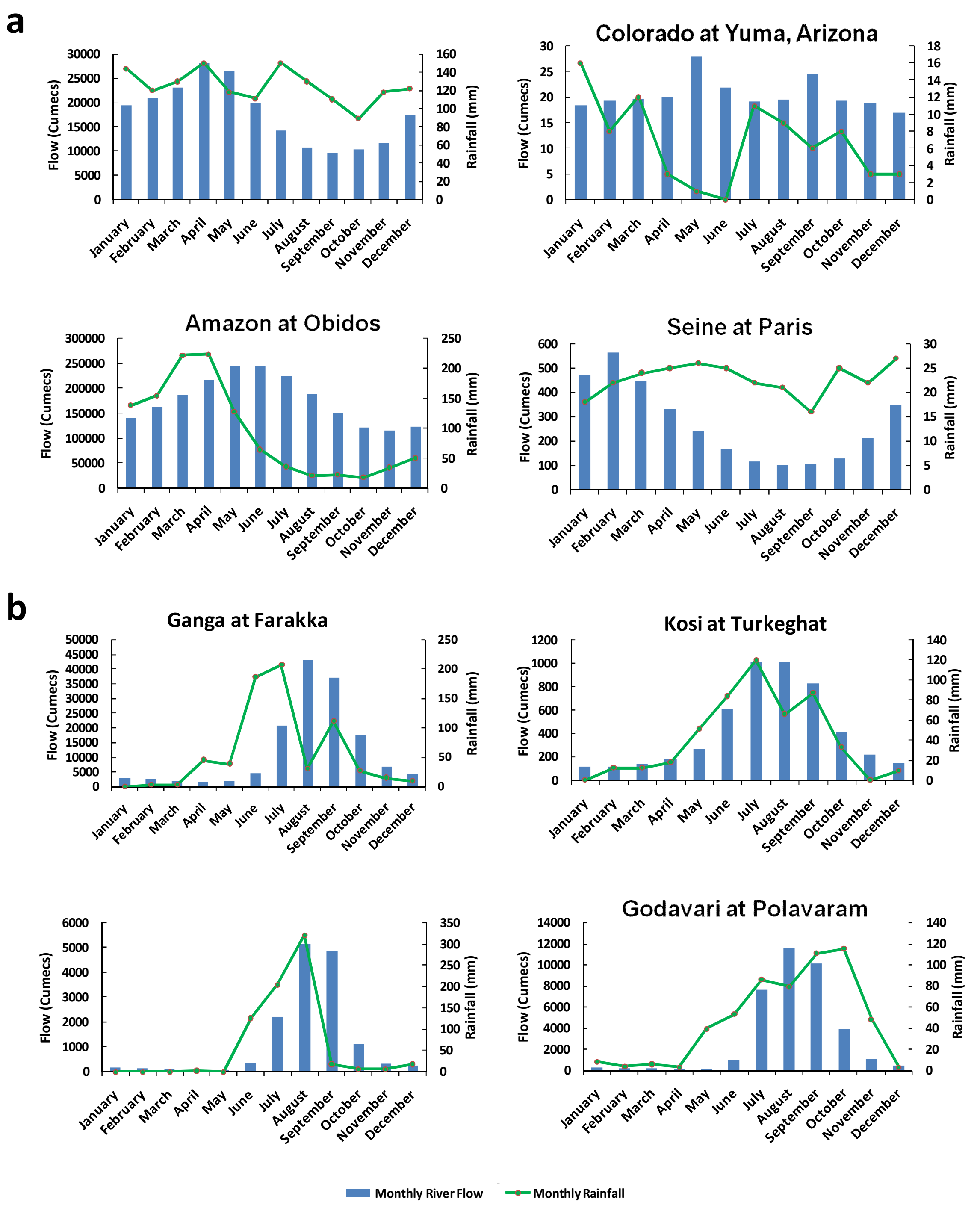

Figure 5: **Monthly Rainfall and River Flow in a Typical Year for (a) Western Rivers, and (b) Indian Rivers**

4. Microbial Pollution Removal Potential of Secondary-level Sewage Treatment Technologies

The water quality analysis, presented in the preceding section, suggests high levels of coliform across all the stretches of the Ganga River despite the implementation of the GAP. It has been widely argued and perceived that the increasing microbial pollution in the river is due to the inappropriate choice of secondary-level sewage treatment techniques, which are largely incapable of removing total and fecal coliforms. In order to substantiate the claim, the microbial removal potential of secondary-level sewage treatment techniques, such as activated sludge process (ASP) and its variants, trickling filter (TF), upflow anaerobic sludge blanket (UASB) reactor, waste stabilization pond (WSP) and its variants, sequencing batch reactor (SBR) and membrane bioreactor (MBR) has been reviewed based on a set of background documents viz. detailed project reports, pollution control board status reports and research publications during the period of 1990-2011. The review mainly focuses on the pathogens removal performance of the full-scale installations treating sewage in the Ganga River basin as well as world-wide except the advanced treatment techniques like SBR and MBR. The microbial pollution removal potential of various secondary-level sewage treatment techniques is presented in Annexure II in detail and summarized in Table 1.

Table 1: Summary of Comparative Evaluation for Pathogen Removal of Various Sewage Treatment Technologies

Parameter/Technology		ASP & Its Variants	TF	UASB	WSP	SBR	MBR
Total Coliform	**Effluent Quality***	10^3-10^7	10^3-10^5	10^5-10^8	10^2-10^6	10^4-10^6	<2-10^2
	Log Removal	1.0-6.0	0.3-3.0	0.3-2.5	1.0-3.0	1.0-2.0	4.0-6.0
Fecal Coliform	**Effluent Quality***	10^3-10^6	10^3-10^6	10^5-10^7	10^2-10^5	10^4-10^5	<2-10
	Log Removal	1.0-4.0	0.3-3.0	0.3-2.0	1.0-3.0	1.0-2.0	4.0-6.0
E. coli	**Effluent Quality***	10^3-10^4	-	10^5-10^6	-	10^2-10^4	<2-10^2
	Log Removal	1.0-3.0	-	0.5-1.0	-	0.2-2.0	5.0-7.0
Fecal Streptococcus	**Effluent Quality***	10^3-10^5	10^3-10^5	-	10^2-10^4	10^3-10^5	<2
	Log Removal	1.0-3.0	0-2.0	-	1.0-2.5	1.0-2.0	>5.0
Helminths Egg	**Effluent Quality***	0-5	-	1-5	0-7	-	0-1
	% Removal	75-100	-	60-99	50-100	-	99-100

*Effluent quality is expressed in MPN/100 ml except Helminths egg (No./L)

It is evident from the review that the potential of pathogen removal in all conventional aerobic processes is more or less of the same order, and are largely incapable of pathogen removal. The pathogen removal in anaerobic processes (e.g. UASB) is generally 1-2 log lower than that of conventional aerobic processes. The advanced treatment techniques like MBR has shown to be highly efficient in removing pathogens. In general, the pathogen removal in the secondary level sewage treatment technologies mainly depends on level of suspended solids, organic contents including humic substances in effluent as a function of solids retention time (SRT) of the system. It has been demonstrated that secondarily-treated sewage effluent contains particle-associated microorganisms in general, particle-associated coliforms (PACs) in particular in form of solids carry over as a function of operating SRT of the biological system (Oliver and Cosgrove, 1975; Severin, 1980; Ho and Bohm, 1981; Qualls *et al*., 1983; Qualls and Johnson, 1985; Scheible, 1987; Cairns, 1993; Emerick and Darby, 1993; Darby *et al*., 1995; Emerick *et al*., 1999; 2000). The level of PACs in secondarily-treated sewage effluent decreases with longer SRTs and vice versa.

The wastewater interception, diversion and treatment schemes under the GAP essentially focused on the reduction in organic pollution, eliminate visible pollution and maintaining aesthetics rather than reduction in microbial pollution in the river. With the implementation of RAP, it was widely perceived that reduction in organic pollution load will have substantial positive impact on DO levels in the river. Accordingly, the secondary wastewater treatment techniques adopted under RAP primarily targeted BOD reduction, whereas the reduction in total and fecal coliforms has been purely incidental. Such technologies adopted under the GAP were capable of treating sewage to conform the 'Class B' bathing standards of the designated best-use classification of inland surface water for DO and BOD only. Moreover, some of the technologies (e.g. UASB) favored under RAP has been proved to be largely ineffective in removal of total and fecal coliform and the effluent is highly unsuitable for further disinfection. Unlike other technologies, the UASB effluent carries high concentration of humic substances and therefore is highly unsuitable for subsequent disinfection. Additionally, consumption of chemicals used for disinfection of UASB effluent will be high as major portions of chemicals would be used for satisfying BOD and instantaneous oxygen demand (IOD). Therefore, the secondary wastewater treatment techniques adopted under RAP are vastly ineffective in removing microbial pollution and the situation warrants adapting tertiary level of treatment of wastewater.

5. Techno-economic Assessment of Treatment Options for Disinfection of Secondary Sewage Effluent

The entire stretch of the Ganga River is subjected to increasing microbial pollution, in terms of total and fecal coliforms as demonstrated by the water quality analysis presented in the preceding section. Disinfection is a crucial unit in wastewater treatment chain to kill pathogenic organisms. Choosing a suitable disinfectant for a wastewater treatment system is dependent on the following criteria: (i) ability to penetrate and destroy infectious agents under normal operating conditions, (ii) effective in pathogens removal under all operating conditions irrespective of degree of pre-treatment employed, (iii) safe and easy in handling, storage, and shipping, (iv) absence of toxic residuals and mutagenic or carcinogenic compounds after disinfection, and (v) affordable capital and operation and maintenance costs. Therefore, the disinfection technique needs to be selected based on the degree of pre-treatment employed and resulting effluent quality from the pre-treatment steps. Under GAP, several disinfection technologies such as chlorination and its variants, solar-based technique, ultraviolet (UV) radiation and ozonation have been employed to sanitize the secondarily-treated sewage effluent.

However, all these methods proved ineffective and resulted in degradation of water quality in terms of microbial pollution as these methods suffer from severe limitations in disinfecting the secondarily-treated sewage effluent. In this context, a techno-economic appraisal of various disinfection options employed under GAP apart from peracetic acid (PAA) has been performed for the secondarily-treated sewage effluent. It is important to note that PAA is a promising new alternative disinfectant. Comprehensive analysis of technicalities like dosage, contact time, pathogens removal potential, effluent quality, process complexity, process reliability, environmental issues apart from economic considerations including capital cost, energy cost, operation and maintenance costs, reinvestment cost, treatment cost, life-cycle cost and land requirement of various disinfection options based on data obtained from various pilot-scale initiatives in the Ganga River basin and elsewhere in the world has been done. The comparative techno-economic evaluation has been summarized in Table 2 for various disinfection options. In order to provide additional factors for further evaluation, key parameters of the disinfection techniques have been relatively compared as shown in the Exhibit 1. The matrix attributes are ranked as Very Good, Good, Average or Poor recognizing that differences between processes are relative, and often, the result of commonly accepted observations.

The disinfection methods can generally be applied to the treated sewage effluent which meets certain quality requirements in terms of suspended solids, organic contents, etc. Various secondary level sewage treatment technologies produce effluent water containing varying level of suspended solids, organic contents including humic substances. Most of the disinfection techniques prove to be ineffective in sanitizing secondarily-treated sewage effluent due to the presence and interference of particle-associated microorganisms in general, particle-associated coliforms (PACs) in particular with the disinfection process (Oliver and Cosgrove, 1975; Severin, 1980; Ho and Bohm, 1981; Qualls *et al*., 1983; Qualls and Johnson, 1985; Scheible, 1987; Cairns, 1993; Emerick and Darby, 1993; Darby *et al*., 1995; Emerick *et al*., 1999; 2000). It has been demonstrated that the presence of PACs in effluent of secondary level sewage treatment processes is a function of prevailing solids retention time (SRT) adopted in the secondary sewage treatment processes with longer SRTs result in decrease of PACs in effluent and vice versa. Chlorination and its variants are most widely used disinfectant for secondarily-treated sewage effluent and efficient under wide range of operating conditions. It is evident from the analysis that chlorination has the least life-cycle cost and it offers a fairly high degree of bactericidal efficiency. The technology is well established and robust and the chemical agent is cheaply and easily available. However, chlorination mode of disinfection requires higher dosage if secondary effluent is partially-/non-nitrified and contains suspended and colloid solids, organic contents including humic substances and compounds with unsaturated bond by exerting additional and immediate chlorine demand (Sung, 1974; Metcalf and Eddy, 2003). Additionally, chlorination may require high dosages if used for anaerobic effluents and effluents with high ammonical and organic nitrogen. Moreover, the chlorine dose for disinfection cannot be increased beyond a certain limit. If the chlorine dose applied is more than prescribed norm it is harmful to aquatic flora and fauna and requires dechlorination of effluent, an additional treatment step. The USEPA recommends for dechlorination to levels of total chlorine less than 0.05 mg/L in effluent discharged to receiving water bodies. Undesirable toxic effects of chlorination on receiving water biota have been vastly documented (Johnson and Jensen, 1986; TFWD, 1986; USEPA, 1986; Rein *et al*., 1992; Hijnen *et al*., 2006; WEF, 2010). Free and combined chlorine elicit a toxic response on aquatic flora and fauna including fish, daphnids, oysters and copepods at extremely low concentrations (Johnson and Jensen, 1986; USEPA, 1986; Hijnen *et al*., 2006; WEF, 2010). Residual chlorine concentrations as low as 0.02 mg/L have reportedly induced toxic effects in aquatic flora and fauna (TFWD, 1986). Dechlorination may be effective in eliminating residual chlorine, but effluent toxicity on aquatic biota will remain due to the presence of less-active and more persistent combined residual chlorine in the dechlorinated effluent (Rein *et al*., 1992). The most acute problem related to chlorination of secondarily-treated sewage effluent is the formation of carcinogenic disinfection byproducts (DBPs). Various natural organic matters (NOMs) such as humic acid, fulvic acid, carbohydrate, proteins, etc. and other anthropogenic organic constituents present in the secondary effluent act as precursors and react with chlorine in the disinfection step to form DBPs, viz. trihalomethane (THM), N-nitrosodimethylamine (NDMA) and haloacetic acids (HAAs), which are considered as carcinogen (Singer, 1999). Both free and combined residual chlorine can produce DBPs that are carcinogenic to humans and harmful to aquatic biota of receiving streams (WEF, 2010). The DBP formation is more acute problem for chlorination of anaerobic effluents like UASB effluent which contains much higher fraction of humic substances which act as precursors. Under most of the circumstances, dechlorination has been shown to be ineffective in eliminating DBPs in chlorinated effluent (WEF, 2010).

Similarly, solar radiation and UV technology are ineffective in disinfecting the secondarily-treated sewage effluent. Disinfection of effluent using solar irradiation is highly dependent of prevailing climatic conditions and therefore microorganism inactivation efficiency fluctuates. Methylene blue, a chemical is generally needed to add to the effluent to increase the light absorption capacity for effective disinfection. An alternative source light energy is required for night operation of the solar disinfection. Many organic and inorganic constituents, viz. suspended and colloidal solids, dissolved organic carbon, humic substances, iron, nitrate and particle-associated microorganisms present in the secondary effluent can absorb and/or scatter solar or UV energy, thus reducing the transmittance of the water. This results in a reduced transmittance (50 to 60% reduction) of solar and UV irradiation and consequently lowers the disinfection efficiency. It has been shown that UV disinfection of effluent from pond treatment system becomes ineffective as a result of low transmittance (often as low as 40 to 50%) during algal blooms and solids washout events (WEF, 2010). The presence of turbidity and SS in secondary effluent and size distribution of SS generally affect the solar and UV irradiation that microorganisms receive as SS can absorb and scatter visible and UV light. Presence of SS and particulates in secondary effluent interferes with the solar and UV disinfection processes to a greater degree as compared to the chemical-assisted disinfection systems. Particulates present in the secondary effluent can shield microorganisms from damaging effects of solar and UV irradiation and thereby reducing the disinfection efficiency as some organisms can become embedded within, or absorbed upon the particles themselves (Darby *et al*., 1993). It has been also demonstrated that organisms can sometimes repair and reverse the destructive effects of UV when applied at low doses (WEF, 2010). The warm temperatures produced by UV lamps promote the precipitation of dissolved organic and inorganic constituents, mainly iron and other metals apart from oil, grease, suspended and colloidal solids present in the effluent and subsequently form an amorphous film on the surface of the quartz sleeves causing the lamp fouling when the lamps are placed directly within the wastewater stream (Mann and Cramer, 1992; Blatchley *et al*., 1996). Secondary effluent with high hardness also causes lamp fouling and thereby reducing the disinfection efficiency of UV technology. Thus, it has been widely suggested that secondary effluent requires an additional treatment step to reduce suspended and colloidal solids and turbidity before applying UV irradiation for disinfection (Andreakis *et al*., 1999; Gómez *et al*., 2007).

Disinfection of secondary effluent employing ozonation proves to be inefficient mainly due to the presence of humic substances. With the increase in humic acid in the effluent, a decrease in reaction rate and subsequently decrease in disinfection efficiency of ozone has been shown (Xiong and Graham, 1992). Ozone also increases the biodegradability of non-biodegradable matter in secondarily-treated wastewater, which can result in regrowth problems (Servais *et al*., 1994). Ozone produces low molecular weight, polar and hydrophilic by-products such as carboxylic acids, aldehydes, ketones and keto acids, which are readily biodegradable resulting in the regrowth potential in the receiving waters (Kitis, 2004). Additionally, ozone mode of disinfection involves comparatively much higher energy requirement and energy cost.

Major limitations associated with peracetic acid (PAA) disinfection of secondarily-treated sewage effluent are the potential microbial regrowth and increase in effluent organic load due to the presence of residual acetic acid in the disinfected effluent (Lefevre *et al*., 1992; Sanchez-Ruiz et al., 1995; Lazarova *et al*., 1998). It has been shown that the disinfection efficiency of PAA decreases with increasing suspended solids (SS) and biochemical oxygen demand (BOD) (Meyer, 1976; Sanchez-Ruiz *et al*., 1995; Colgan and Gehr, 2001; Stampi *et al*., 2001) of wastewater to be disinfected. PAA becomes ineffective as disinfectant while secondarily-treated effluent SS are more than 50 mg/L (Lefevre *et al*., 1992; Lazarova *et al*., 1998). Although PAA is considered to decompose to harmless products and to form little to no by-products that are toxic or mutagenic, the possibility that it could form DBPs cannot be completely ignored (Crathorne *et al*., 1991; Kitis, 2004). It has been shown that, under certain conditions like high PAA dosages, sufficient contact times, and adequate concentration of organic and mineral constituents in the secondary effluent, formation of halogenated DBP like aldehydes is a problem (Crathorne *et al*., 1991). Another disadvantage of the use of PAA as disinfectant is its high cost, which is partly as result of limited production capacity worldwide (Kitis, 2004).

It is imperative from the comprehensive techno-economic appraisal that all these disinfection techniques suffer from several limitations and are more or less ineffective in disinfecting the secondarily-treated sewage effluent. The present Indian paradigm of wastewater treatment employing primary and secondary treatment techniques is vastly inadequate and ineffective and hence any attempt to adopt disinfection of secondarily-treated sewage effluent is bound to be unsatisfactory. Therefore, the comprehensive techno-economic appraisal and the limitations of various techniques for disinfection of secondary sewage effluent provide more substance to the argument for adapting tertiary level of wastewater treatment in India, the Ganga River basin in particular.

Table 2: Comparative Evaluation of Various Technologies for Disinfection of Secondary Sewage Effluent

S No.	Assessment Parameter/Technology	Chlorination & Its Variants	Solar	UV	Ozone	PAA
1	**Contact Time**					
	Nominal Range (min.)	1-150	20-60	0.1-0.7	0.25-60	15-120
	Average Range (min.)	30-60	30-40	0.2-0.5	10-20	50-70
2	**Disinfection Dose**					
	Nominal Range	6-20 mg/L	2400-7200 mW-s/cm^2	2-200 mW-s/cm^2	3-20 mg/L	0.6-100 mg/L
	Average Range	10-15 mg/L	3600-4800 mW-s/cm^2	30-50 mW-s/cm^2	5-10 mg/L	5-20 mg/L
3	**Inactivation Efficiency**					
	Effluent Fecal Coliform, *MPN/100 ml*	<1000	<1000	<200	<50	<1000
	Fecal Coliform, *log unit*	upto 4<5	upto 2<3	upto 4<5	upto 4<5	upto 4<5
4	**Average Capital Cost,** *Rs Lacs/MLD*	**16.4**	**71.8**	**30.8**	**41.0**	**10.0**
	Civil Works, *% of capital costs*	60	60	40	35	30
	E&M Works, *% of capital costs*	40	40	60	65	70
	Average Area Requirement, *m^2 /MLD*	25	160	15	10	30
5	**Energy Costs**					
	Total Power Requirement, *kWh/ MLD (avg)*	**18.8**	**33.6**	**63.9**	**246.2**	**15.5**
	Daily Power Cost, *(@Rs 4.0/KWhr), Rs/MLD/hr*	3.10	5.60	10.70	41.00	2.60
	Yearly Power Cost , *Rs Lacs PA/MLD*	0.27	0.49	0.93	3.59	0.23
6	**Annual Operation & Maintenance Costs,** *Rs Lacs/MLD*	**3.7**	**9.0**	**8.3**	**7.4**	**22.2**
	Avg. Land Cost Assumed, *Rs Lacs/m^2*	0.01	0.01	0.01	0.01	0.01
	Unit Land Cost, *Rs Lacs/MLD*	0.25	1.60	0.15	0.10	0.30
	Unit Capital Cost including Land Cost, *Rs Lacs/MLD*	16.65	73.40	30.95	41.10	10.30
	Rate of compound interest, *r (adopted), % per year*	10	10	10	10	10
7	**Treatment Cost^,** *Rs/KL*	**1.61**	**5.05**	**3.38**	**3.50**	**6.44**
8	**Unit Life Cycle Costs for 15 Years,** *Rs Lacs/MLD*	**44.8**	**141.9**	**94.1**	**97.4**	**179.2**

^ excluding land cost

Exhibit 1: Assessment of Technology Options for Disinfection of Secondary Sewage Effluent

Criteria/Technology	Chlorination & Its Variants	Solar	UV	Ozone	PAA
Degree of Pre-treatment Required	Low	Very High	High	High	Medium
Relative Complexity of Technology	Low	Low	Medium	Very High	Low
Performance in Terms of Inactivation Efficiency					
Bactericidal	High	High	Very High	Very High	High
Virucidal	Medium	Low	Very High	Very High	Low
Cysticidal	Low	Low	Low	High	Low
Potential of Persistent Residual (Potential of No Regrowth)	High	Low	High	High	Low
Potential of Meeting the RAPs Coliform Standards	High	Medium	Very High	Very High	High
Performance Reliability	Very High	Medium	High	Very High	Low
Environmental Impacts					
Potential of Hazardous By-products Formation	Very High	Low	Low	Medium	Low
Potential of Posing Fish Toxicity	High	Low	Low	Low	Medium
Potential of Creating Corrosion	High	Low	Low	Very High	Medium
Safety Concerns					
Potential of Low Level of On-site Safety Risks	Low	Very High	Very High	Medium	High
Potential of Low Level of Safety Risks during Transportation	Low	Very High	Very High	High	Medium
Potential of Low Level of Safety Risks to STP Staff/Operator	Low	Very High	High	Medium	Medium
Potential of No Adverse Impacts on Surrounding Community	Low	Very High	Very High	High	High
Potential of Low Energy Requirement	Very High	High	Medium	Low	Very High
Potential of Low Land Requirement	Medium	Low	High	Very High	Medium
Potential of Low Capital Cost	Very High	Low	High	Medium	Very High
Potential of Low Recurring Cost	Medium	Very High	High	Medium	Low
Potential of Low Reinvestment Cost	High	Low	Low	High	High
Potential of Low Level of Skill in O&M	Very High	High	High	Medium	High
Track Record	Very High	Medium	High	Very High	Low
Typical Capacity Range, MLD	All Flows	Smaller	Smaller - Medium	Medium - Larger	All Flows

Low	Medium	High	Very High

6. Concluding Remarks and Recommendations

Based on the comprehensive analysis of general flow pattern and water quality of the Ganga River, microbial pollution removal potential of secondary-level sewage treatment technologies and the performance of commonly adopted treatment technologies for disinfection of secondary sewage effluent, following inferences and general recommendations can be made:

- The water quality analysis of some routinely monitored parameters (DO, BOD_5, total and fecal coliforms) in the Ganga River suggests that the river is subjected to increasing microbial pollution despite the implementation of intervention schemes and regulatory mechanisms under the GAP. The situation gets further aggravated by the low river flows during most of the periods in a year due to the prevailing climatic and monsoon characteristics and results in further degradation of the water quality of the river in terms of microbial pollution (fecal contamination).
- The primary goals of the wastewater treatment schemes under the GAP seem to be the reduction in organic pollution, eliminate visible pollution and maintaining aesthetics rather than reduction in microbial pollution in the river. The secondary wastewater treatment techniques adopted under RAP primarily target BOD reduction, whereas the reduction in total and fecal coliforms has been purely incidental. Some of the technologies (e.g. UASB) favored under RAP has been proved to be ineffective in removal of total and fecal coliforms and the effluent is highly unsuitable for further disinfection. Hence, the present Indian paradigm of wastewater treatment employing primary and secondary treatment techniques is vastly ineffective and hence any attempt to adopt disinfection of secondarily-treated sewage effluent is bound to be unsatisfactory.
- The comprehensive analysis presented in the report, therefore, clearly suggest and point out towards adapting the tertiary level of wastewater treatment in India, the Ganga River basin in particular. Zero discharge municipality/city concept (i.e. completely prohibit the disposal of treated or untreated wastewater into surface water bodies) needs to be implemented in the Ganga Basin by recycling and reusing tertiary-treated effluent for 'non-potable, non-human contact' uses within the municipality/city.
- The combination of two or more disinfection processes in the treatment chain should be adopted as multiple disinfection processes in series can provide an additional margin of safety through complementary inactivation of various types of pathogens. Ozonation followed by UV treatment and/or chlorination can be adopted to enhance the robustness of the treatment chain with the multiple barrier approach to disinfection.

References:

Alcocer, L., Lugo, A., López, A. and Sánchez, M.R. (1993) Efficiency of a waste stabilization pond system in a subtropical area of Mexico, *Revista Internacional de Contaminación Ambiental*, 9(1), pp. 29-36.

Al-Sa`ed, R. (2007) Pathogens Assessment in Reclaimed Effluent Used for Industrial Crops Irrigation, *International Journal of Environmental Research and Public Health*, 4(1), pp. 68-75.

Andreakis, A., Mamais, D., Christoulas, D. and Kabylafka, S. (1999) Ultraviolet disinfection of secondary and tertiary effluent in the Mediterranean region, *Water Science and Technology,* 40(4-5), pp. 253-260.

Arrojo, B., Mosquera-Corra, A., Garrid, J.M., Mdndez, R., Ficara, E. and Malpei, F. (2005) A membrane coupled to a sequencing batch reactor for water reuse and removal of coliform bacteria, *Desalination*, 179, pp. 109-116.

Awuah, E. and Abrokwa, K.A. (2008) Performance evaluation of the UASB sewage treatment plant at James Town (Mudor), Accra, In: *Proceedings of the 33rd WEDC International Conference*, Accra, Ghana.

Blatchley III, E.R., Bastian, K.C., Duggirala, R.K., Alleman, J.E., Moore, M. and Schuerch, P. (1996) Ultraviolet irradiation and chlorination/dechlorination for municipal wastewater disinfection: Assessment of performance limitations, *Water Environment Research*, 68, pp. 194-204.

Bolzonella, D., Fatone, F., di Fabio, S. and Cecchi, F. (2010) Application of membrane bioreactor technology for wastewater treatment and reuse in the Mediterranean region: Focusing on removal efficiency of non-conventional pollutants, *Journal of Environmental Management*, 91(12), pp. 2424-2431.

Brenner, A., Shandalov, S., Messalem, R., Yakirevich, A., Oron, G. and Rebhun, M. (2000) Wastewater reclamation for agricultural reuse in Israel: Trends and experimental results, *Water, Air and Soil Pollution*, 123, pp. 167-182.

Brissaud, F., Lazarova, V., Ducoup, C., Josep,h C., Levine, B. and Tournoud, M.G. (2000) Hydrodynamic behaviour and faecal coliform removal in a maturation pond, *Water Science and Technology*, 42(10-11), pp. 343-348.

Cairns, W.L. (1993) Comparing disinfection by ultraviolet light and chlorination – The implications of mechanism for practice, In: *Proceedings of the Planning, Design, and Operation Effluent Disinfection System Specialty Conference*, Water Environment Federation, Whippany, NJ, p. 555.

Chae, S.R., Kang, S.T., Lee, S.M., Lee, E.S., Oh, S.E., Watanabe, Y. and Shin, H.S. (2007) High reuse potential of effluent from an innovative vertical submerged membrane bioreactor treating municipal wastewater, *Desalination*, 202(1–3), pp. 83-89.

Chauret, C., Springthorpe, S. and Sattar, S. (1999) Fate of Cryptosporidium oocysts, Giardia cysts and microbial indicators during wastewater treatment and anaerobic sludge digestion, *Canadian Journal of Microbiology*, 45, pp. 257-262.

Colgan, S. and Gehr, R. (2001) Disinfection, *Water Environment and Technology*, 13, pp. 29-33.

Côté, P., Buisson, H., Pound, C. and Arakaki, G. (1997) Immersed membrane activated sludge for the reuse of municipal wastewater, *Desalination*, 113(2–3), pp. 189-196.

CPCB (2005) *Status of Sewage Treatment in India*, Central Pollution Control Board (CPCB), New Delhi, November 2005. In website: http://www.cpcb.nic.in/newitems/12.pdf

Crathorne, B., Fawell, J., Irving, T., Harris, N., Denny, S. and Whitmore, T. (1991) *Sewage Disinfection: By-Product Formation, Ecotoxicology and Microbiological Efficacy*, Report NR 2727, Medmenham, UK: Water Research Centre.

Darby, J.L., Heath, M., Jacangelo, J., Loge, F., Swain, P. and Tchobanoglous, G. (1995) *Comparative Efficiencies of UV Irradiation to Chlorination: Guidance for Achieving Optimal UV Performance*, Project 91-WWD-1 Report, Water Environment Research Foundation, Alexandria, VA.

Darby, J.L., Snider, K.E. and Tchobanoglous, G. (1993) Ultraviolet disinfection for wastewater reclamation and reuse subject to restrictive standards, *Water Environment Research*, 65, pp. 169-180.

Dixo, N.G.H., Gambrill, M.P., Catunda, P.F.C. and van Haandel, A.C. (1995) Removal of pathogenic organisms from the effluent of an up flow anaerobic digester using waste stabilisation ponds, *Water Science and Technology*, 31(12), pp. 275-284.

El-Gohary, F.A., Nasr, F.A. and El-Hawaary, S. (1998) Performance assessment of a wastewater treatment plant producing effluent for irrigation in Egypt, *The Environmentalist*, 18, pp. 87-93.

El-Hamouri, B., Khallayoune, K., Bouzoubaa, K., Rhallabi, N. and Chalabi, M. (1994) High-rate algal pond performances in faecal coliforms and helminth egg removals, *Water Research*, 28(1), pp. 171-174.

Ellouze, M., Saddoud, A., Dhouib, A. and Sayadi, S. (2009) Assessment of the impact of excessive chemical additions to municipal wastewaters and comparison of three technologies in the removal performance of pathogens and toxicity, *Microbiological Research*, 164(2), pp. 133-148.

Emerick, R.W. and Darby, J.L. (1993) Ultraviolet light disinfection of secondary effluents: Predicting performance based on water quality parameters, In: *Proceedings of the Planning, Design, and Operation Effluent Disinfection System Specialty Conference*, Water Environment Federation, Whippany, NJ.

Emerick, R.W., Loge, F., Ginn, T. and Darby, J.L. (2000) Modeling the inactivation of particle-associated coliform bacteria, *Water Environment Research*, 72(4), pp. 432-438.

Emerick, R.W., Loge, F.J., Thompson, D. and Darby, J.L. (1999) Factors influencing ultraviolet disinfection performance Part II: Association of coliform bacteria with wastewater particles, *Water Environment Research*, 71(6), pp. 1178-1187.

Filipkowska, Z. and Krzemieniewski, M. (1998) Effectiveness of Indicatory Microorganism Removal on Trickling Filter with Biofilm in Magnetic Field, *Polish Journal of Environmental Studies*, 7(4), pp. 201-205.

Friedler, E., Kovalio, R. and Ben-Zvi, A. (2006) Comparative study of the microbial quality of greywater treated by three on-site treatment systems, *Environmental Technology*, 27(6), pp. 653-663.

Gómez, A., Plaza, F., Garralón, G., Pérez, J. and Gómez, M.A. (2007) A comparative study of tertiary wastewater treatment by physico-chemical-UV process and macrofiltration-ultrafiltratioin technologies, *Desalination*, 202, pp. 369-376.

Guo, W., Vigneswaran, S., Ngo, H.H., Xing, W. and Goteti, P. (2008) Comparison of the performance of submerged membrane bioreactor (SMBR) and submerged membrane adsorption bioreactor (SMABR), *Bioresource Technology*, 99(5), pp. 1012-1017.

Herrera-Robledo, M., Cid-León, D.M., Morgan-Sagastume, J.M. and A. Noyola (2011) Biofouling in an anaerobic membrane bioreactor treating municipal sewage, *Separation and Purification Technology*, 81, pp. 49-55.

Hijnen, W.A.M., Beerendonk, E.F. and Medema, G.J. (2006) Inactivation of UV radiation for viruses, bacteria, and protozoan (oo)cysts in water: a review, *Water Research*, 40, pp. 3-22.

Hirani, Z.M., DeCarolis, J.F., Adhamb, S.S. and Jacangelo, J.G. (2010) Peak flux performance and microbial removal by selected membrane bioreactor systems, *Water Research*, 44(8), pp. 2431-2440.

Ho, K.W.A. and Bohm, P. (1981) UV disinfection of tertiary and secondary effluents, *Canadian Journal of Water Pollution Research*, 16, pp. 33-36.

Hodgson, B. and Paspaliasis, P. (1996) Melbourne Water’s wastewater treatment lagoons: Design modifications to reduce odours and enhance nutrient removal, *Water Science and Technology*, 33(7), pp. 57-164.

Hodgson, I.O.A. (2000) Treatment of domestic sewage at Akuse (Ghana), *Water SA,* 26(3), pp. 413-415.

Hodgson, I.O.A. (2007) Performance of the Akosombo waste stabilization ponds in Ghana, *Ghana Journal of Science*, 47, pp. 35-44.

Jamwal, P. and Mittal, A.K. (2010) Reuse of treated sewage in Delhi city: Microbial evaluation of STPs and reuse options, *Resources, Conservation and Recycling*, 54(4), pp. 211-221.

Johnson, J.D. and Jensen, J.N. (1986) THM and TOX formation: routes, rates and precursors, *J. AWWA*, 78(4), pp. 156-162.

Jong, J., Lee, J., Kim, J., Hyun, K., Hwang, T., Park, J. and Choung, Y. (2010) The study of pathogenic microbial communities in graywater using membrane bioreactor, *Desalination*, 250(2), pp. 568-572.

Keller, R., Passamani-Franca, R.F., Passamani, F., Vaz, L., Cassini, S.T., Sherrer, N., Rubim, K., Sant'Ana, T.D. and Gonçalves, R.F. (2004) Pathogen removal efficiency from UASB + BF effluent using conventional and UV post-treatment systems, *Water Science and Technology*, 50(1), pp. 1-6.

Kistemann, T., Rind, E., Rechenburg, A., Koch, C., Claßen, T., Herbst, S., Wienand, I. and Exner, M. (2008) A comparison of efficiencies of microbiological pollution removal in six sewage treatment plants with different treatment systems, *International Journal of Hygiene and Environment Health*, 211, pp. 534-545.

Kitis, M. (2004) Disinfection of wastewater with peracetic acid: a review, *Environment International*, 30, pp. 47-55.

Komesli, O.T., Teschner, K., Hegemann, W. and Gokcay, C.F. (2007) Vacuum membrane applications in domestic wastewater reuse, *Desalination*, 215, pp. 22-28.

Kouraa, A., Fethi , F., Fahde , A., Lahlou , A. and Ouazzani N. (2002) Reuse of urban wastewater treated by a combined stabilisation pond system in Benslimane (Morocco), *Urban Water*, 4, pp. 373-378.

Kuai, L., Kerstens, W., Cuong, N.P. and Verstraete, W. (1999) Treatment of Domestic Wastewater by Enhanced Primary Decantation and Subsequent Naturally Ventilated Trickling Filtration, *Water, Air and Soil Pollution*, 113(1-4), pp. 43-62.

Lazarova, V., Janex, M.L., Fiksdal, L., Oberg, C., Barcina, I. and Pommepuy, M. (1998) Advanced wastewater disinfection technologies: Short and long term efficiency, *Water Science and Technology*, 38(12), pp. 109-117.

Lefevre, F., Audic, J.M. and Ferrand, F. (1992) Peracetic acid disinfection of secondary effluents discharged off coastal seawater, *Water Science and Technology*, 25(12), pp. 155-164.

Ling, T.Y., Apun, K. and Zainuddin, S.R. (2009) Performance of a pilot-scale biofilters and constructed wetland with ornamental plants in greywater treatment, *World Applied Sciences Journal*, 6(11), pp. 1555-1562.

Mandi, L., Ouazzani, N., Bouhoum, K. and Boussaid, A. (1993) Wastewater treatment by stabilization ponds with and without macrophytes under arid climate, *Water Science and Technology*, 28(10), pp. 177-181.

Mann, M.A. and Cramer, J.A. (1992) Disinfecting with ultraviolet radiation: retrofitting three North Carolina treatment plants, *Water Environment and Technology*, 12, pp. 40-45.

Mara, D.D., Cogman, C.A., Simkins, P. and Schembri, M.C.A. (1998) Performance of the Burwarton Estate waste stabilization ponds, *Journal of the Chartered Institution of Water and Environmental Management*, 12(4), pp. 260-264.

Marti, E., Monclús, H., Jofre, J., Rodriguez-Roda, I., Comas, J. and Balcázar, J.L. (2011) Removal of microbial indicators from municipal wastewater by a membranebioreactor (MBR), *Bioresource Technology*, 102, pp. 5004-5009.

Martinez-Sosa, D., Helmreich, B., Netter, T., Paris, S., Bischof, F. and Horn, H. (2011) Anaerobic submerged membrane bioreactor (AnSMBR) for municipal wastewater treatment under mesophilic and psychrophilic temperature conditions, *Bioresource Technology*, 102, pp. 10377-10385.

Merz, C., Scheumann, R., El-Hamouri, B. and Kraume, M. (2007) Membrane bioreactor technology for the treatment of greywater from a sports and leisure club, *Desalination*, 215, pp. 37-43.

Metcalf & Eddy, Inc. (2003) *Wastewater Engineering*, 4th ed.; McGraw-Hill: New York.

Meyer, E. (1976) Disinfection of sewage waters from rendering plants by means of peracetic acid, *Journal of Hygiene, Epidemiology, Microbiology & Immunology*, 21, pp. 266-273.

Mungray, A.K. and Patel, K. (2011) Coliforms removal in two UASB+ASP based systems, *International Biodeterioration and Biodegradation*, 65(1), pp. 23-28.

Ng, W.J., Sim, T.S., Ong, S.L., Ng, K.Y., Ramasamy, M. and Tan K.N. (1993) Efficiency of sequencing batch reactor (SBR) in the removal of selected microorganisms from domestic sewage, *Water Research*, 27(10), pp. 1591-1600.

Ngari, J.M., Kotut, K. and Okemo, P. (2011) Potential threat to wildlife posed by enteric pathogens from Nakuru sewage treatment plant, *African Journal of Health Sciences*, 18(1-2), pp. 85-95.

NRCD (2010) Performance data on sewage treatment plants (STPs) in India, National River Conservation Directorate, Ministry of Environments and Forests, Government of India. In website: http://wqmrivers.nic.in

Oakley, S.M., Pocasangre, A., Flores, C., Monge, J. and Estrada, M. (2000) Waste stabilization pond use in Central America: The experiences of El Salvador, Guatemala, Honduras and Nicaragua, *Water Science and Technology*, 42(10), pp. 51-58.

Olańczuk-Neyman, K., Stosik-Fleszar, H. and Mikołajski, S. (2001) Evaluation of Indicator Bacteria Removal in Wastewater Treatment Processes, *Polish Journal of Environmental Studies*, 10(6), pp. 457-461.

Oliver, B.G. and Cosgrove, E.G. (1975) The disinfection of sewage treatment plant effluents using ultraviolet light, *Canadian Journal of Chemical Engineering*, 53, pp. 170-174.

Ottoson, J., Hansen, A., Björlenius, B., Norder, H. and Stenström, T.A. (2006) Removal of viruses, parasitic protozoa and microbial indicators in conventional and membrane processes in a wastewater pilot plant, *Water Research*, 40(7), pp. 1449-1457.

Papadimitriou, C.A., Papatheodoulou, A., Takavakoglou, V., Zdragas, A., Samaras, P., Sakellaropoulos, G.P., Lazaridou, M. and Zalidis, G. (2010) Investigation of protozoa as indicators of wastewater treatment efficiency in constructed wetlands, *Desalination*, 250(1), pp. 378-382.

Pettigrew, L., Angles, M. and Nelson, N. (2010) Pathogen removal by a membrane bioreactor, *Water,* 37(6), pp. 44-51.

Qualls, R.G., and Johnson, J.D. (1985) Modeling and efficiency of ultraviolet disinfection systems, *Water Research*, 19(8), pp. 1039-1046.

Qualls, R.G., Flynn, M.P. and Johnson, J.D. (1983) The role of suspended particles in ultraviolet disinfection, *Journal of Water Pollution Control Federation*, 57, pp. 1006-1011.

Qureshi, M.A. and Qureshi, A.A. (1990) Efficiency of removal of coliforms, faecal coliforms and coliphages in the Tubli sewage treatment plant, Bahrain, *Water Research*, 24(12), pp. 1459-1461

Rein, D.A., Jamesson, G.M. and Monteith, R.A. (1992) Toxicity effects of alternate disinfection processes, In: *Proceedings of the 65th Annual Water Environment Federation Technical Exposition and Conference*, New Orleans, Louisiana, September 20–24, 1992, Water Environment Federation: Alexandria, Virginia.

Rose, J.B., Dickson, L.J., Farrah, S.R. and Carnahan, R.P. (1996) Removal of pathogenic and indicator microorganisms by a full-scale water reclamation facility, *Water Research*, 30(11), pp. 2785-2797.

Saddoud, A., Ellouze, M., Dhouib, A. and Sayadi, S. (2007) Anaerobic membrane bioreactor treatment of domestic wastewater in Tunisia, *Desalination*, 207(1-3), pp. 205-215.

Saleem, M., Bukhari, A.A. and Al-Malack, M.H. (2000) Removal efficiencies of indicator micro-organisms in the Al-Khobar wastewater treatment plant, *Environmental Engineering Science*, 17(4), pp. 227-232.

Samie, A., Obi, C. L., Igumbor, J. O. and Momba, M. N. B. (2009) Focus on 14 sewage treatment plants in the Mpumalanga Province, South Africa in order to gauge the efficiency of wastewater treatment, *African Journal of Biotechnology*, 8(14), pp. 3276-3285.

Sanchez-Ruiz, C., Martinez-Royano, S. and Tejero-Monzon, I. (1995) An evaluation of the efficiency and impact of raw wastewater disinfection with peracetic acid prior to ocean discharge, *Water Science and Technology*, 32, pp. 159-166.

Scheible, O.K. (1987) Development of a rationally based design protocol for the ultraviolet light disinfection process, *Journal of Water Pollution Control Federation*, 59(1), pp. 25-31.

Seghezzo, L. (2004) *Anaerobic Treatment of Wastewater in Subtropical Regions*, Ph.D. Thesis, Wageningen University, The Netherlands.

Servais, P., Billen, P. and Bouillot, P. (1994) Biological colonization of granular activated carbon filters in drinking water, *Journal of Environmental Engineering*, 120(4), pp. 888-899.

Severin, B.F. (1980) Disinfection of municipal effluents with ultraviolet light, *Journal of Water Pollution Control Federation*, 52(7), pp. 2007-2018.

Singer P.C. (Ed.) (1999) Formation and control of disinfection by-products in drinking water, *American Water Works Association*, pp. 53-63, 65-70, 179-204.

Stampi, S., De Luca, G. and Zanetti, F. (2001) Evaluation of the efficiency of peracetic acid in the disinfection of sewage effluents, *Journal of Applied Microbiology*, 91, pp. 833-838.

Sung, R.D. (1974) *Effects of Organic Constituents in Wastewater on the Chlorination Process*, Ph.D. Thesis, Department of Civil Engineering, University of California, Davis, CA.

TFWD (1986) *Wastewater Disinfection: Manual of Practice No. FD-10*, Task Force on Wastewater Disinfection, Water Pollution Control Federation.

Tonani, K.A.A., Julião, F.C., Trevilato, T.M.B.,Takayanagui, A.M.M., Bocio, A., Domingo, J.L. and Segura-Muñoz, S.I. (2011) behavior of metals, pathogen parasites, and indicator bacteria in sewage effluents during biological treatment by activated sludge, *Biological Trace Element Research*, 143(2), pp. 1193-1201.

Tyagi, V.K., Sahoo, B.K., Khursheed, A., Kazmi, A.A., Ahmad, Z. and Chopra, A.K. (2010) Fate of coliforms and pathogenic parasite in four full-scale sewage treatment systems in India, *Environmental Monitoring and Assessment*, 181(1-4), pp. 123-135.

Ueda, T. and Hata, K. (1999) Domestic wastewater treatment by a submerged membrane bioreactor with gravitational filtration, *Water Research*, 33(12), pp. 2888-2892.

Ueda, T. and Horan, N.J. (2000) Fate of indigenous bacteriophage in a membrane bioreactor, *Water Research*, 34(7), pp. 2151-2159.

USEPA (1986) *Municipal Wastewater Disinfection Design Manual,* EPA-625/1-86-021; U.S. Environmental Protection Agency (USEPA): Cincinnati, Ohio.

Van der Steen, P., Brenner, A., Van Buuren, J. and Oron, G. (2000) Post-treatment of UASB reactor effluent in an integrated duckweed and stabilization pond system, *Water Research*, 33(3), pp. 615-620.

WEF (2010) *Design of Municipal Wastewater Treatment Plants: WEF Manual of Practice No. 8 ASCE Manuals and Reports on Engineering Practice No. 76*, Fifth Edition, WEF Press/McGraw-Hill Publication, Alexandria, VA: Water Environment Federation.

Winward, G.P., Avery, L.M., Frazer-Williams, R., Pidou, M., Jeffrey, P., Stephenson, T. and Jefferson, B. (2008) A study of the microbial quality of grey water and an evaluation of treatment technologies for reuse, *Ecological Engineering*, 32(2), pp. 187-197.

Xiong, F. and Graham, N.J.D. (1992) Removal of atrazine through ozonation in the presence of humic substances, *Ozone Science and Engineering*, 14(3), pp. 263-268.

Zahid, W.M. and El-Shafai, S.A. (2011) Use of cloth-media filter for membrane bioreactor treating municipal wastewater, *Bioresource Technology*, 102(3), pp. 2193-2198.

Zanetti, F., Luca, G.D. and Sacchetti, R. (2010) Performance of a full-scale membrane bioreactor system in treating municipal wastewater for reuse purposes, *Bioresource Technology*, 101, pp. 3768-3771.

Zhang, K. and Farahbakhsh, K. (2007) Removal of native coliphages and coliform bacteria from municipal wastewater by various wastewater treatment processes: Implications to water reuse, *Water Research*, 41(12), pp. 2816-2824.

Annexure I

Table A1.1: Conformation of Ganga River Water Quality with the Designated Best-use Classification of Inland Surface Water (CPCB) during Dry Season for the Period 1986 – 2010

S. No.	Location	Confidence Level (%) of Observations Conforming the Designated Best-use Classification of Inland Surface Water (CPCB)								
		Dissolved Oxygen (DO)			Biochemical Oxygen Demand (BOD_5)			Total Coliform (TC)		
		A (≥6 mg/L)	B (≥5 mg/L)	C (≥4 mg/L)	A (≤2 mg/L)	B (≤3 mg/L)	C (≤3 mg/L)	A (≤5.00E+01 MPN/100ml)	B (≤5.00E+02 MPN/100ml)	C (≤5.00E+03 MPN/100ml)
1	Uttarkashi u/s (Bhagirathi)	100	100	100	100	100	100	99.9	100	100
2	Uttarkashi d/s (Bhagirathi)	100	100	100	100	100	100	69.2	100	100
3	Devprayag u/s (Bhagirathi)	100	100	100	100	100	100	50.0	100	100
4	Devprayag u/s (Alaknanda)	100	100	100	100	100	100	50.0	100	100
5	Devprayag d/s (Ganga)	100	100	100	100	100	100	21.2	100	100
6	Ranipur u/s (Ganga)	100	100	100	100	100	100	0.03	100	100
7	Ranipur d/s (Ganga)	100	100	100	100	100	100	0.03	100	100
8	Rishikesh u/s	100	100	100	100	100	100	0.03	100	100
9	Rishikesh d/s	100	100	100	100	100	100	0.03	100	100
10	Haridwar u/s	100	100	100	100	100	100	0.03	100	100
11	Har-ki-Paudi	100	100	100	100	100	100	0.03	100	100
12	Lalta Rao	100	100	100	100	100	100	0.03	100	100
13	Dam Kothi	100	100	100	100	100	100	0.03	88.5	100
14	Mishrpur	100	100	100	0.1	100	100	0.03	0.03	100
15	Bijnore u/s (Ganga)	100	100	100	100	100	100	0.03	100	100
16	Bijnore d/s (Ganga)	100	100	100	99.5	100	100	0.03	94.5	100
17	Garhmukteshwar u/s	100	100	100	4.5	100	100	0.03	0.1	100
18	Garhmukteshwar d/s	100	100	100	100	100	100	0.03	1.4	100
19	Anoopshahr u/s (Ganga)	100	100	100	38.2	100	100	0.03	46.0	100
20	Anoopshahr d/s (Ganga)	100	100	100	8.1	100	100	0.03	0.2	100
21	Fatehgarh u/s	100	100	100	0.03	91.9	91.9	5.5	5.5	5.5
22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	100	100	100	0.03	0.03	0.03	0.5	0.5	0.5
23	Kannauj d/s (a/c with Kali)	100	100	100	0.03	0.03	0.03	0.5	0.5	0.5
24	Kanpur u/s (Bithoor)	100	100	100	0.03	1.8	1.8	2.9	2.9	3.6
25	Kanpur d/s (Shuklaganj)	100	100	100	0.03	0.03	0.03	0.03	0.03	0.03
26	Kanpur d/s (Jane Village)	54.0	100	100	0.03	0.03	0.03	5.5	5.5	5.5
27	Allahbad u/s (Ujahni, Fatehpur)	100	100	100	0.03	0.03	0.03	0.03	0.03	11.5
28	Bathing Ghats at Sangam	100	100	100	0.03	0.1	0.1	0.3	0.3	3.6
29	D/s Deehaghat	100	100	100	0.03	0.1	0.1	0.1	0.1	5.5
30	Vindhyachal, Pakka Ghat	100	100	100	0.03	65.5	65.5	0.03	0.05	6.7
31	Varanasi u/s	100	100	100	0.03	3.6	3.6	0.03	0.03	9.7
32	Dashashawmedh Ghat	100	100	100	0.03	0.8	0.8	0.03	0.03	0.03
33	D/s at Kaithy	99.9	100	100	0.03	1.1	1.1	0.03	0.03	0.05
34	Near Malviya Bridge	100	100	100	0.03	0.03	0.03	0.05	0.05	0.1

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S. No.	Location	Confidence Level (%) of Observations Conforming the Designated Best-use Classification of Inland Surface Water (CPCB)								
		Dissolved Oxygen (DO)			Biochemical Oxygen Demand (BOD_5)			Total Coliform (TC)		
		A (≥6 mg/L)	B (≥5 mg/L)	C (≥4 mg/L)	A (≤2 mg/L)	B (≤3 mg/L)	C (≤3 mg/L)	A (≤5.00E+01 MPN/100ml)	B (≤5.00E+02 MPN/100ml)	C (≤5.00E+03 MPN/100ml)
35	Tarighat	100	100	100	0.03	0.03	0.03	0.03	0.03	0.3
36	Buxar u/s	100	100	100	97.7	100	100	0.03	0.03	0.03
37	Buxar d/s	100	100	100	99.9	100	100	0.03	0.03	0.03
38	Chapra u/s (Ghaghra)	100	100	100	100	100	100	0.03	0.03	2.3
39	Chapra d/s (Chapra)	100	100	100	9.7	100	100	0.03	0.03	0.03
40	Arrah u/s (River Gangi)	100	100	100	2.9	100	100	0.03	0.03	0.03
41	Arrah d/s (River Gangi)	21.2	98.2	100	0.03	0.03	0.03	0.03	0.03	0.03
42	Koliwar (River Sone)	100	100	100	100	100	100	0.03	0.03	4.5
43	Hajipur u/s (River Gandak)	100	100	100	100	100	100	0.03	0.03	0.03
44	Hajipur d/s (River Gandak)	100	100	100	100	100	100	0.03	0.03	13.6
45	Patna u/s	100	100	100	100	100	100	2.3	2.3	2.9
46	Patna d/s	100	100	100	99.9	100	100	4.5	5.5	5.5
47	Fatuha u/s	100	100	100	93.3	100	100	0.03	0.03	0.03
48	Fatuha d/s	100	100	100	93.3	100	100	0.03	0.03	0.03
49	Barh u/s	100	100	100	46.0	100	100	0.03	0.03	0.03
50	Barh d/s	100	100	100	98.2	100	100	0.03	0.03	0.1
51	Mokama u/s	100	100	100	2.9	100	100	0.03	0.03	0.03
52	Mokama d/s	100	100	100	69.2	100	100	0.03	0.03	0.03
53	D/s Bata - McDowell	100	100	100	99.9	100	100	0.03	0.03	0.03
54	Munger u/s	100	100	100	100	100	100	0.03	0.03	0.03
55	Munger d/s	100	100	100	100	100	100	0.03	0.03	0.03
56	Sultanganj u/s	100	100	100	100	100	100	0.03	0.03	0.03
57	Sultanganj d/s	100	100	100	100	100	100	0.03	0.03	0.03
58	Bhagalpur u/s	100	100	100	100	100	100	0.03	0.03	0.03
59	Bhagalpur d/s	100	100	100	99.9	100	100	0.03	0.03	0.03
60	D/s Champanala	18.4	98.6	100	0.03	0.03	0.03	0.03	0.03	0.03
61	Kahalgaon u/s	100	100	100	100	100	100	0.05	0.1	0.6
62	Kahalgaon d/s	100	100	100	100	100	100	0.03	0.03	0.03
63	D/s NTPC Drain	100	100	100	99.4	100	100	0.8	0.8	3.6
64	Sahebganj u/s	100	100	100	100	100	100	0.03	0.03	0.03
65	Sahebganj d/s	100	100	100	100	100	100	0.03	0.03	0.03
66	Rajmahal d/s	100	100	100	100	100	100	0.03	0.03	4.5
67	Berhampore (Middle)	100	100	100	100	100	100	0.03	0.03	15.9
68	Palta (Middle)	100	100	100	65.5	100	100	0.03	0.03	0.03
69	Dakshineswar (Middle)	100	100	100	1.1	100	100	0.03	0.03	0.03
70	Uluberia (Middle)	100	100	100	42.1	100	100	0.03	0.03	0.03

Table A1.2: Conformation of Ganga River Water Quality with the Designated Best-use Classification of Inland Surface Water (CPCB) during Wet Season for the Period 1986 – 2010

S. No.	Location	Confidence Level (%) of Observations Conforming the Designated Best-use Classification of Inland Surface Water (CPCB)								
		Dissolved Oxygen (DO)			Biochemical Oxygen Demand (BOD_5)			Total Coliform (TC)		
		A (≥6 mg/L)	B (≥5 mg/L)	C (≥4 mg/L)	A (≤2 mg/L)	B (≤3 mg/L)	C (≤3 mg/L)	A (≤5.00E+01 MPN/100ml)	B (≤5.00E+02 MPN/100ml)	C (≤5.00E+03 MPN/100ml)
1	Uttarkashi u/s (Bhagirathi)	100	100	100	100	100	100	9.7	100	100
2	Uttarkashi d/s (Bhagirathi)	100	100	100	100	100	100	5.5	100	100
3	Devprayag u/s (Bhagirathi)	100	100	100	100	100	100	34.5	100	100
4	Devprayag u/s (Alaknanda)	100	100	100	100	100	100	30.9	100	100
5	Devprayag d/s (Ganga)	100	100	100	100	100	100	21.2	100	100
6	Ranipur u/s (Ganga)	100	100	100	100	100	100	0.03	100	100
7	Ranipur d/s (Ganga)	100	100	100	100	100	100	0.03	100	100
8	Rishikesh u/s	100	100	100	78.8	100	100	0.03	100	100
9	Rishikesh d/s	100	100	100	100	100	100	0.03	100	100
10	Haridwar u/s	100	100	100	100	100	100	0.03	100	100
11	Har-ki-Paudi	100	100	100	100	100	100	0.03	100	100
12	Lalta Rao	100	100	100	100	100	100	0.03	100	100
13	Dam Kothi	100	100	100	69.2	100	100	0.03	65.5	100
14	Mishrpur	100	100	100	0.03	57.9	57.9	0.03	0.03	100
15	Bijnore u/s (Ganga)	100	100	100	100	100	100	0.03	100	100
16	Bijnore d/s (Ganga)	100	100	100	98.9	100	100	0.03	100	100
17	Garhmukteshwar u/s	100	100	100	0.3	100	100	0.03	0.03	100
18	Garhmukteshwar d/s	100	100	100	0.03	100	100	0.03	0.03	100
19	Anoopshahr u/s (Ganga)	100	100	100	90.3	100	100	0.03	18.4	100
20	Anoopshahr d/s (Ganga)	100	100	100	15.9	100	100	0.03	0.1	100
21	Fatehgarh u/s	100	100	100	78.8	100	100	4.5	4.5	5.5
22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	100	100	100	0.3	84.1	84.1	9.7	9.7	9.7
23	Kannauj d/s (a/c with Kali)	100	100	100	2.9	99.7	99.7	5.5	5.5	5.5
24	Kanpur u/s (Bithoor)	100	100	100	86.4	100	100	4.5	4.5	5.5
25	Kanpur d/s (Shuklaganj)	91.9	100	100	0.3	97.1	97.1	0.03	0.03	0.3
26	Kanpur d/s (Jane Village)	97.7	100	100	0.03	0.03	0.03	15.9	15.9	15.9
27	Allahbad u/s (Ujahni, Fatehpur)	100	100	100	0.03	5.5	5.5	0.03	0.05	2.3
28	Bathing Ghats at Sangam	100	100	100	9.7	98.9	98.9	2.9	2.9	5.5
29	D/s Deehaghat	100	100	100	0.8	38.2	38.2	0.03	0.03	0.1
30	Vindhyachal, Pakka Ghat	99.8	100	100	9.7	98.2	98.2	2.3	2.3	3.6
31	Varanasi u/s	100	100	100	8.1	72.6	72.6	8.1	8.1	11.5
32	Dashashawmedh Ghat	72.6	100	100	4.5	38.2	38.2	0.1	0.1	0.1
33	D/s at Kaithy	100	100	100	46.0	100	100	0.1	0.1	0.3
34	Near Malviya Bridge	100	100	100	0.2	13.6	13.6	0.03	0.03	0.05
35	Tarighat	100	100	100	0.5	8.1	8.1	0.8	0.8	2.9

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S No.	Location	Confidence Level (%) of Observations Conforming the Designated Best-use Classification of Inland Surface Water (CPCB)								
		Dissolved Oxygen (DO)			Biochemical Oxygen Demand (BOD_5)			Total Coliform (TC)		
		A (≥6 mg/L)	B (≥5 mg/L)	C (≥4 mg/L)	A (≤2 mg/L)	B (≤3 mg/L)	C (≤3 mg/L)	A (≤5.00E+01 MPN/100ml)	B (≤5.00E+02 MPN/100ml)	C (≤5.00E+03 MPN/100ml)
36	Buxar u/s	90.3	100	100	100	100	100	0.03	0.03	0.03
37	Buxar d/s	100	100	100	99.9	100	100	0.03	0.03	0.03
38	Chapra u/s (Ghaghra)	100	100	100	100	100	100	0.03	0.03	0.03
39	Chapra d/s (Chapra)	84.1	100	100	100	100	100	0.03	0.03	0.03
40	Arrah u/s (River Gangi)	61.8	100	100	1.8	99.2	99.2	0.03	0.03	0.03
41	Arrah d/s (River Gangi)	0.03	42.1	100	0.03	2.9	2.9	0.03	0.03	0.03
42	Koliwar (River Sone)	100	100	100	100	100	100	0.03	0.03	0.03
43	Hajipur u/s (River Gandak)	99.7	100	100	100	100	100	0.05	0.1	0.6
44	Hajipur d/s (River Gandak)	100	100	100	100	100	100	0.03	0.03	0.2
45	Patna u/s	100	100	100	100	100	100	0.03	0.03	0.03
46	Patna d/s	93.3	99.2	100	99.9	100	100	0.03	0.03	0.03
47	Fatuha u/s	61.8	100	100	100	100	100	0.03	0.03	0.03
48	Fatuha d/s	65.5	100	100	99.5	100	100	0.03	0.03	0.03
49	Barh u/s	97.7	100	100	100	100	100	0.2	0.3	0.8
50	Barh d/s	34.5	100	100	100	100	100	0.03	0.03	1.4
51	Mokama u/s	86.4	100	100	57.9	100	100	0.03	0.03	0.03
52	Mokama d/s	93.3	100	100	100	100	100	0.03	0.03	0.03
53	D/s Bata - McDowell	100	100	100	100	100	100	0.03	0.03	0.03
54	Munger u/s	98.6	100	100	100	100	100	0.03	0.03	0.1
55	Munger d/s	81.6	100	100	100	100	100	0.03	0.03	0.03
56	Sultanganj u/s	91.9	100	100	100	100	100	0.03	0.03	0.03
57	Sultanganj d/s	75.8	100	100	100	100	100	0.05	0.1	0.2
58	Bhagalpur u/s	99.4	100	100	100	100	100	0.03	0.03	0.1
59	Bhagalpur d/s	93.3	100	100	100	100	100	0.2	0.2	0.8
60	D/s Champanala	21.2	99.5	100	0.8	57.9	57.9	0.03	0.03	0.03
61	Kahalgaon u/s	100	100	100	100	100	100	0.03	0.03	0.03
62	Kahalgaon d/s	99.9	100	100	100	100	100	0.03	0.03	0.1
63	D/s NTPC Drain	100	100	100	100	100	100	0.6	0.6	1.1
64	Sahebganj u/s	24.5	100	100	100	100	100	0.1	0.1	0.5
65	Sahebganj d/s	50.0	100	100	100	100	100	0.2	0.2	0.8
66	Rajmahal d/s	100	100	100	100	100	100	0.03	0.03	0.03
67	Berhampore (Middle)	100	100	100	99.5	100	100	0.03	0.03	0.03
68	Palta (Middle)	65.5	100	100	98.6	100	100	0.03	0.03	0.03
69	Dakshineswar (Middle)	34.5	100	100	50.0	100	100	0.03	0.03	0.03
70	Uluberia (Middle)	72.6	91.9	98.6	97.7	100	100	0.03	0.03	0.03

Table A1.3: Overall Conformation of Ganga River Water Quality with the Designated Best-use Classification of Inland Surface Water (CPCB) for the Period 1986 – 2010

S. No.	Location	Confidence Level (%) of Observations Conforming the Designated Best-use Classification of Inland Surface Water (CPCB)								
		Dissolved Oxygen (DO)			Biochemical Oxygen Demand (BOD_5)			Total Coliform (TC)		
		A (≥6 mg/L)	B (≥5 mg/L)	C (≥4 mg/L)	A (≤2 mg/L)	B (≤3 mg/L)	C (≤3 mg/L)	A (≤5.00E+01 MPN/100ml)	B (≤5.00E+02 MPN/100ml)	C (≤5.00E+03 MPN/100ml)
1	Uttarkashi u/s (Bhagirathi)	100	100	100	100	100	100	54.0	100	100
2	Uttarkashi d/s (Bhagirathi)	100	100	100	100	100	100	13.6	100	100
3	Devprayag u/s (Bhagirathi)	100	100	100	100	100	100	38.2	100	100
4	Devprayag u/s (Alaknanda)	100	100	100	100	100	100	38.2	100	100
5	Devprayag d/s (Ganga)	100	100	100	100	100	100	13.6	100	100
6	Ranipur u/s (Ganga)	100	100	100	100	100	100	0.03	100	100
7	Ranipur d/s (Ganga)	100	100	100	100	100	100	0.03	100	100
8	Rishikesh u/s	100	100	100	100	100	100	0.03	100	100
9	Rishikesh d/s	100	100	100	100	100	100	0.03	100	100
10	Haridwar u/s	100	100	100	100	100	100	0.03	100	100
11	Har-ki-Paudi	100	100	100	100	100	100	0.03	100	100
12	Lalta Rao	100	100	100	100	100	100	0.03	100	100
13	Dam Kothi	100	100	100	100	100	100	0.03	88.5	100
14	Mishrpur	100	100	100	0.03	100	100	0.03	0.03	100
15	Bijnore u/s (Ganga)	100	100	100	100	100	100	0.03	100	100
16	Bijnore d/s (Ganga)	100	100	100	100	100	100	0.03	99.7	100
17	Garhmukteshwar u/s	100	100	100	0.1	100	100	0.03	0.03	100
18	Garhmukteshwar d/s	100	100	100	99.2	100	100	0.03	0.03	100
19	Anoopshahr u/s (Ganga)	100	100	100	57.9	100	100	0.03	30.9	100
20	Anoopshahr d/s (Ganga)	100	100	100	4.5	100	100	0.03	0.03	100
21	Fatehgarh u/s	100	100	100	0.3	100	100	2.3	2.3	2.3
22	Kannauj u/s (a/c with Ramganga & b/c with Kali)	100	100	100	0.03	0.03	0.03	3.6	3.6	3.6
23	Kannauj d/s (a/c with Kali)	100	100	100	0.03	0.03	0.03	1.1	1.1	1.1
24	Kanpur u/s (Bithoor)	100	100	100	0.03	72.6	72.6	0.6	0.6	1.1
25	Kanpur d/s (Shuklaganj)	100	100	100	0.03	0.03	0.03	0.03	0.03	0.03
26	Kanpur d/s (Jane Village)	24.2	100	100	0.03	0.03	0.03	15.9	15.9	15.9
27	Allahbad u/s (Ujahni, Fatehpur)	100	100	100	0.03	0.03	0.03	0.03	0.03	1.1
28	Bathing Ghats at Sangam	100	100	100	0.03	0.8	0.8	0.1	0.2	1.1
29	D/s Deehaghat	100	100	100	0.03	0.1	0.1	0.03	0.03	0.5
30	Vindhyachal, Pakka Ghat	100	100	100	0.03	94.5	94.5	0.3	0.5	2.3
31	Varanasi u/s	100	100	100	0.03	9.7	9.7	2.3	2.9	9.7
32	Dashashawmedh Ghat	100	100	100	0.03	2.3	2.3	0.03	0.03	0.03
33	D/s at Kaithy	100	100	100	0.03	34.5	34.5	0.03	0.03	0.03
34	Near Malviya Bridge	100	100	100	0.03	0.03	0.03	0.03	0.03	0.03
35	Tarighat	100	100	100	0.03	0.05	0.05	0.03	0.03	0.1

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S. No.	Location	Confidence Level (%) of Observations Conforming the Designated Best-use Classification of Inland Surface Water (CPCB)								
		Dissolved Oxygen (DO)			Biochemical Oxygen Demand (BOD_5)			Total Coliform (TC)		
		A (≥6 mg/L)	B (≥5 mg/L)	C (≥4 mg/L)	A (≤2 mg/L)	B (≤3 mg/L)	C (≤3 mg/L)	A (≤5.00E+01 MPN/100ml)	B (≤5.00E+02 MPN/100ml)	C (≤5.00E+03 MPN/100ml)
36	Buxar u/s	100	100	100	100	100	100	0.03	0.03	0.03
37	Buxar d/s	100	100	100	100	100	100	0.03	0.03	0.03
38	Chapra u/s (Ghaghra)	100	100	100	100	100	100	0.03	0.03	0.03
39	Chapra d/s (Chapra)	100	100	100	65.5	100	100	0.03	0.03	0.03
40	Arrah u/s (River Gangi)	100	100	100	0.3	100	100	0.03	0.03	0.03
41	Arrah d/s (River Gangi)	1.1	96.4	100	0.03	0.03	0.03	0.03	0.03	0.03
42	Koliwar (River Sone)	100	100	100	100	100	100	0.03	0.03	0.03
43	Hajipur u/s (River Gandak)	100	100	100	100	100	100	0.03	0.03	0.03
44	Hajipur d/s (River Gandak)	100	100	100	100	100	100	0.03	0.03	0.2
45	Patna u/s	100	100	100	100	100	100	1.1	1.1	1.4
46	Patna d/s	100	100	100	100	100	100	1.1	1.1	1.4
47	Fatuha u/s	100	100	100	100	100	100	0.03	0.03	0.03
48	Fatuha d/s	100	100	100	99.7	100	100	0.03	0.03	0.03
49	Barh u/s	100	100	100	86.4	100	100	0.03	0.03	0.03
50	Barh d/s	100	100	100	100	100	100	0.03	0.03	0.03
51	Mokama u/s	100	100	100	46.0	100	100	0.03	0.03	0.03
52	Mokama d/s	100	100	100	99.7	100	100	0.03	0.03	0.03
53	D/s Bata - McDowell	100	100	100	100	100	100	0.03	0.03	0.03
54	Munger u/s	100	100	100	100	100	100	0.03	0.03	0.03
55	Munger d/s	100	100	100	100	100	100	0.03	0.03	0.03
56	Sultanganj u/s	100	100	100	100	100	100	0.03	0.03	0.03
57	Sultanganj d/s	100	100	100	100	100	100	0.03	0.03	0.03
58	Bhagalpur u/s	100	100	100	100	100	100	0.03	0.03	0.03
59	Bhagalpur d/s	100	100	100	100	100	100	0.03	0.03	0.03
60	D/s Champanala	11.5	99.9	100	0.03	0.1	0.1	0.03	0.03	0.03
61	Kahalgaon u/s	100	100	100	100	100	100	0.03	0.03	0.03
62	Kahalgaon d/s	100	100	100	100	100	100	0.03	0.03	0.03
63	D/s NTPC Drain	100	100	100	100	100	100	0.05	0.1	0.3
64	Sahebganj u/s	100	100	100	100	100	100	0.03	0.03	0.5
65	Sahebganj d/s	100	100	100	100	100	100	0.03	0.03	0.03
66	Rajmahal d/s	100	100	100	100	100	100	0.03	0.03	0.03
67	Berhampore (Middle)	100	100	100	100	100	100	0.03	0.03	0.03
68	Palta (Middle)	100	100	100	91.9	100	100	0.03	0.03	0.03
69	Dakshineswar (Middle)	100	100	100	2.9	100	100	0.03	0.03	0.03
70	Uluberia (Middle)	93.3	100	100	72.6	100	100	0.03	0.03	0.03

Annexure II

Table A2.1: Pathogen Removal Potential of Sewage Treatment Plants (STPs) based on Activated Sludge Process and Its Variants

Location	Treatment Variation	TC (MPN/100 ml)			FC (MPN/100 ml)			*E. coli* (MPN/100 ml)			FS (MPN/100 ml)			Helminths Egg (No./L)			Reference	Remarks, if any
		I	E	Log R	I	E	Log R	I	E	Log R	I	E	Log R	I	E	%R		
Tubli, Bahrain, Arabian Gulf*	EA	8.0E+06-1.3E+08		>2.0	2.1E+06-1.0E+07		>2.0										Qureshi *et al.* (1990)	*TC and FC in CFU/100 ml
St Petersburg, Florida*	ASP	8.2E+07±2.3E+07	1.5E+06±1.6E+06	1.8	2.2E+07±0.6E+07	1.9E+05±0.2E+05	2.1									75.0	Rose *et al.* (1996)	*TC and FC in CFU/100 ml
Helwan, Egypt	ASP	9.1E+07-4.0E+10	7.3E+01-1.1E+04	4.0	3.6E+07-2.0E+10	3.6E+01-1.1E+04	4.0				3.5E+07-4.5E+10	2.4E+03-1.1E+04	4.0				El-Gohary *et al.* (1998)	
Al-Khobar, Saudi Arabia	ASP			1.7-2.0			1.7-2.0										Saleem *et al.* (2000)	
Nangal Punjab, India	ASP	1.6E+08	8.0E+04	3.3	1.6E+08	4.0E+04	3.6			1.05-2.00							CPCB (2005)	
Beur, Patna, India	ASP	5.0E+07	1.7E+05	2.5	1.1E+07	8.0E+05	1.1										CPCB (2005)	
Saidpur, Patna, India	ASP	1.6E+08	1.1E+06	2.2	1.4E+07	5.0E+05	1.5										CPCB (2005)	
Raipur Khurd, Chandigarh, India	ASP	5.0E+08	1.1E+06	2.7	3.0E+08	5.0E+05	2.8										CPCB (2005)	
Narela, Delhi, India	ASP	1.7E+07	1.1E+05	2.2	1.7E+07	4.0E+03	3.6										CPCB (2005)	
Snowdon, Shimla, India	EA	9.0E+08	1.4E+06	2.8	1.7E+08	9.0E+05	2.3										CPCB (2005)	
Dhalli, Shimla	EA	9.0E+07	1.4E+06	2.8	5.0E+07	1.4E+06	1.6										CPCB (2005)	
Summer Hill Shimla, India	EA	3.5E+07	2.0E+05	2.2	2.0E+07	2.0E+05	2.0										CPCB (2005)	
Maliana, Shimla, India	EA	5.0E+08	8.0E+05	2.8	3.0E+08	5.0E+05	2.8										CPCB (2005)	
North Disposal, Shimla, India	EA	5.0E+08	2.2E+06	2.4	1.7E+08	1.4E+06	2.1										CPCB (2005)	
Swisttal, Germany*	ASP	6.3E+07±1.0E+08	2.0E+04±1.6E+04	3.4±1.0				9.0E+06±5.4E+06	6.0E+03±7.2E+03	3.2±1.0	2.1E+06±1.1E+06	2.0E+03±3.2E+03	3.1±0.9				Kistemann *et al.* (2008)	**E. coli* and FS in CFU/100 ml
Heinersreuth, Germany*	ASP	3.6E+07±4.3E+07	3.0E+04±2.4E+04	3.1±1.2				1.3E+07±3.9E+06	4.0E+03±3.2E+03	3.5±0.4	3.3E+06±1.6E+06	4.0E+03±4.0E+03	2.9±0.3				Kistemann *et al.* (2008)	**E. coli* and FS in CFU/100 ml
Kirchheim, Germany*	ASP	2.5E+07±1.7E+07	5.7E+05±5.1E+05	1.6±0.5				7.0E+06±2.8E+06	8.5E+04±1.1E+05	1.9±0.8	1.3E+06±7.8E+05	2.0E+05±4.2E+05	0.8±1.0				Kistemann *et al.* (2008)	**E. coli* and FS in CFU/100 ml
Rheinbach, Germany*	ASP	1.2E+07±1.1E+07	4.0E+04±3.2E+04	2.5±0.8				3.0E+06±3.3E+06	1.6E+04±4.8E+03	2.3±0.7	1.8E+06±2.0E+06	4.0E+03±2.0E+03	2.7±0.5				Kistemann *et al.* (2008)	**E. coli* and FS in CFU/100 ml
Mahres, Sfax, Tunisia*	ASP	1.2E+04-6.1E+05	6.0E+03-1.7E+05	0.6	6.0E+03-2.0E+05	4.0E+03-3.0E+04	0.9				2.0E+03-5.0E+05	1.7E+03-1.3E+05	0.7	19.0±3.0	5.0±1.0	74.1	Ellouze *et al.* (2009)	*TC and FC in CFU/100 ml
Ksour-Essaf, Sfax, Tunisia*	ASP	1.1E+04-6.3E+04	4.0E+03-5.5E+03	0.8	4.0E+03-2.8E+04	1.0E+03-1.0E+03	0.9				1.0E+03-3.5E+04	2.0E+03-5.0E+03	0.8	11.0±3.2	4.5±1.2	59.0	Ellouze *et al.* (2009)	*TC and FC in CFU/100 ml
Matsulu, South Africa *	ASP	1.4E+06	8.0E+01	4.2	7.2E+03	6.0E+02	1.1										Samie *et al.* (2009)	*TC and FC in CFU/100 ml
Sabie, South Africa*	ASP	2.4E+05	5.4E+02	2.7	1.6E+04	1.8E+02	2.0										Samie *et al.* (2009)	*TC and FC in CFU/100 ml
Machadodorp, South Africa*	ASP	3.2E+06	6.5E+04	1.7	9.7E+04	7.2E+03	1.1										Samie *et al.* (2009)	*TC and FC in CFU/100 ml

TC: Total coliform; FC: Fecal coliform; FS: Fecal streptococcus; I: Influent; E: Effluent; Log R: Log removal; %R: Percent removal

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Location	Treatment Variation	TC (MPN/100 ml)			FC (MPN/100 ml)			*E. coli* (MPN/100 ml)			FS (MPN/100 ml)			Helminths Egg (No./L)			Reference	Remarks, if any
		I	E	Log R	I	E	Log R	I	E	Log R	I	E	Log R	I	E	%R		
Belfast, South Africa*	ASP	7.2E+05	1.2E+02	3.8	2.0E+05	5.0E+01	3.6										Samie *et al.* (2009)	*TC and FC in CFU/100 ml
Dullstroom, South Africa*	ASP	5.4E+06	6.0E+00	6.0	5.8E+04	7.0E+00	3.9										Samie *et al.* (2009)	*TC and FC in CFU/100 ml
Middleburg, South Africa*	ASP	2.3E+06	4.3E+01	4.7	1.3E+03	1.5E+01	1.9										Samie *et al.* (2009)	*TC and FC in CFU/100 ml
Haridwar, Uttarakhand, India	ASP	3.2E+07±6.9E+07	1.9E+05±6.9E+07	2.2	9.9E+06±2.4E+07	5.9E+04±2.8E+06	2.2				6.1E+05±1.4E+07	6.5E+03±2.0E+05	2.0	43.4±17.8	1.7±1.1	96.1	Tyagi *et al.* (2010)	
Vasant Kunj, Delhi, India	EA	2.7E+07±4.9E+07	1.8E+04±5.1E+04	3.0	1.1E+07±2.2E+07	8.7E+03±1.8E+04	3.0				7.8E+05±1.4E+06	1.6E+03±4.9E+03	2.7	42.3±11.4	1.2±2.1	97.2	Tyagi *et al.* (2010)	
Ribeirão Preto, Sao Paulo, Brazil	ASP													1.2E+03-5.8E+04	0-7.0E+03	27.0-100	Tonani *et al.* (2011)	
Kondli, Delhi, India	ASP				7.4E+07	1.6E+04	3.7				4.2E+06	7.8E+03	2.7				Jamwal and Mittal (2010)	
Yamuna Vihar, Delhi, India	ASP				1.0E+07	1.2E+05	1.9				9.1E+05	5.1E+04	1.3				Jamwal and Mittal (2010)	
Rithala I, Delhi, India	ASP				3.5E+06	2.3E+05	1.2				7.8E+06	2.5E+05	1.5				Jamwal and Mittal (2010)	
Coronation Pillar, Delhi, India	ASP				1.0E+06	6.9E+04	1.2				1.5E+04	4.0E+02	1.6				Jamwal and Mittal (2010)	
Okhla, Delhi, India	ASP				8.1E+06	1.9E+05	1.6				2.8E+06	3.1E+04	2.0				Jamwal and Mittal (2010)	
Nilothi, Delhi, India	ASP				1.4E+07	1.6E+04	3.0				2.0E+06	1.7E+04	2.1				Jamwal and Mittal (2010)	
Keshopur, Delhi, India	ASP				1.9E+07	1.5E+05	2.1				7.8E+06	8.7E+05	0.9				Jamwal and Mittal (2010)	
Papankallan, Delhi, India	ASP				4.0E+06	2.6E+05	1.2				4.4E+06	1.7E+05	1.4				Jamwal and Mittal (2010)	
Vasant Kunj I, Delhi, India	EA				2.0E+07	4.0E+04	2.7				3.0E+07	1.3E+04	3.4				Jamwal and Mittal (2010)	
Mehrauli, Delhi, India	EA				1.3E+07	1.0E+03	4.1				1.8E+06	8.3E+02	3.3				Jamwal and Mittal (2010)	
Nazafgarh, Delhi, India	EA				3.2E+06	7.6E+03	2.6				2.0E+05	2.6E+03	1.9				Jamwal and Mittal (2010)	
Rithala II, Delhi, India	High-rate Aeration				3.5E+06	4.4E+05	0.9				7.8E+06	3.4E+05	1.4				Jamwal and Mittal (2010)	
Allahabad, India	ASP	1.2E+08±2.4E+08	5.3E+06±8.0E+06	1.3	6.2E+07±1.5E+08	3.4E+06±8.7E+06	1.3										NRCD (2010)	
Bhagwanpur, Varanasi, India	ASP	1.1E+08±1.2E+08	4.8E+06±7.8E+06	1.4	5.3E+07±1.1E+08	3.6E+06±7.5E+06	1.2										NRCD (2010)	
DLW, Varanasi, India	ASP	1.6E+08±1.2E+08	5.7E+06±9.8E+06	1.4	8.4E+07±6.4E+07	4.3E+06±7.5E+06	1.3										NRCD (2010)	
Dinapur, Varanasi, India	ASP	1.8E+08±3.1E+08	2.4E+07±3.3E+07	0.9	7.1E+07±1.1E+08	8.9E+06±1.2E+07	0.9										NRCD (2010)	
Jajmau, Kanpur, India	ASP	6.2E+07±6.3E+07	1.2E+06±6.3E+05	1.7	5.2E+06±4.8E+06	3.2E+05±2.4E+05	1.2										NRCD (2010)	

TC: Total coliform; FC: Fecal coliform; FS: Fecal streptococcus; I: Influent; E: Effluent; Log R: Log removal; %R: Percent removal

Table A2.2: Pathogen Removal Potential of Sewage Treatment Plants (STPs) based on Trickling Filter

Location	Treatment Variation	TC (MPN/100 ml)			FC (MPN/100 ml)			*E. coli* (MPN/100 ml)			FS (MPN/100 ml)			Helminths Egg (No./L)			Reference	Remarks, if any
		I	E	Log R	I	E	Log R	I	E	Log R	I	E	Log R	I	E	%R		
Kortowo, Poland	TF	9.0E+04-2.5E+06	4.5E+04-2.5E+05	0.3-1.4	1.4E+04-1.4E+06	2.5E+03-1.4E+05	0.26-1.00				4.0E+04-2.5E+05	2.5E+03-1.4E+05	0-2.0				Filipkowska and Krzemieniewski (1998)	
Gent, Belgium*	TF	7.9E+04±6.3E+01	1.6E+02±3.2E+01	2.7	7.9E+03±4.0E+01	1.3E+02±1.6E+01	1.8				7.9E+03±4.0E+01	1.0E+02±7.9E+00	1.9				Kuai *et al.* (1999)	*TC, FC and FS in CFU/100 ml
T. T. Nagar, Bhopal, India	TF	1.7E+03	2.0E+02	0.9	2.0E+01	<2.0E+00	-										CPCB (2005)	
Howrah, West Bengal, India	TF					1.1E+06											CPCB (2005)	
Chandannagore, West Bengal, India	TF					9.0E+05											CPCB (2005)	
Kalyani, West Bengal, India	TF					2.2E+04											CPCB (2005)	
Baranagar, West Bengal, India	TF					5.0E+06											CPCB (2005)	
Serampore, West Bengal, India	TF					3.0E+06											CPCB (2005)	
Witbank, South Africa*	TF	2.5E+06	2.8E+04	2.0	2.2E+04	3.6E+05	-										Samie *et al.* (2009)	*TC and FC in CFU/100 ml, Increase in effluent FC number
Lydenburg, South Africa*	TF	1.6E+06	1.6E+03	3.0	1.2E+05	4.8E+02	2.4										Samie *et al.* (2009)	*TC and FC in CFU/100 ml
Kuching City, Malaysia*	TF				1.4E+06	6.3E+01	4.4										Ling *et al.* (2009)	*FC in CFU/100 ml
Coronation Pillar, Delhi, India	TF				1.0E+06	3.3E+04	1.5				1.5E+04	4.5E+02	1.5				Jamwal and Mittal (2010)	
Nakuru, Kenya	TF+MP				5.4E+07-1.6E+08	2.0E+02-2.3E+04	3.7										Ngari *et al.* (2011)	

TC: Total coliform; FC: Fecal coliform; FS: Fecal streptococcus; I: Influent; E: Effluent; Log R: Log removal; %R: Percent removal

Table A2.3: Pathogen Removal Potential of Sewage Treatment Plants (STPs) based on Upflow Anaerobic Sludge Blanket Reactor

Location	Treatment Variation	TC (MPN/100 ml)			FC (MPN/100 ml)			*E. coli* (MPN/100 ml)			FS (MPN/100 ml)			Helminths Egg (No./L)			Reference	Remarks, if any
		I	E	Log R	I	E	Log R	I	E	Log R	I	E	Log R	I	E	%R		
Amazonas, Brazil	UASB+SP (Pilot Plant)						4.0									100	Dixo *et al.* (1995)	
Negev Desert, Israel	UASB+SP (Pilot Plant)				6.3E+05±1.3E+06	3.3E+02±5.0E+03	2.4-3.3										Van der Steen *et al.* (1999)	
Salta, Argentina	UASB+SP (Pilot Plant)						6.0										Seghezzo (2004)	
Vitoria ES, Brazil	UASB							1.0E+07	2.0E+06	0.7				19.5	5.0	74.3	Keller *et al.* (2004)	
Yamunanagar I,Haryana, India	UASB+FPU	3.0E+06	1.7E+05	1.3	2.3E+06	1.1E+05	1.3										CPCB (2005)	
Yamunanagar II,Haryana, India	UASB+FPU	1.7E+06	8.0E+05	0.3	8.0E+05	4.0E+05	0.3										CPCB (2005)	
Karnal, Haryana, India	UASB+FPU	1.3E+07	4.0E+05	1.5	8.0E+06	2.0E+05	1.6										CPCB (2005)	
Sonipat, Haryana, India	UASB+FPU	3.0E+08	5.0E+05	2.8	4.0E+07	3.0E+05	2.1										CPCB (2005)	
Ghaziabad, India*	UASB	1.3E+06	2.4E+06	-	1.7E+06	2.0E+05	0.9										CPCB (2005)	*Increase in effluent TC number
Sector 54, Noida, India	UASB+FPU	2.3E+07	3.0E+05	1.9	8.0E+06	8.0E+04	2.0										CPCB (2005)	
Sector 50, Noida, India	UASB+FPU	3.0E+07	4.0E+05	1.9	1.7E+07	4.0E+05	1.6										CPCB (2005)	
Agra, Uttar Pradesh, India	UASB+FPU	9.0E+07	5.0E+06	1.3	3.0E+07	5.0E+06	0.8										CPCB (2005)	
Rishikesh, Uttarakhand, India	UASB+FPU	5.0E+08	9.0E+07	0.7	2.4E+08	3.0E+07	0.9										CPCB (2005)	
Trans Hindon Area, Ghaziabad, India	UASB+FPU	-	2.4E+06	-	-	1.3E+05	-										CPCB (2005)	
James Town(Mudor), Accra	UASB				6.8E+05-1.0E+06	1.4E+05-2.9E+05	0.54-0.7										Awuah and Abrokwa (2008)	
Saharanpur, Uttar Pradesh, India	UASB+FPU	1.2E+07±1.5E+07	8.9E+04±9.6E+04	2.2	3.1E+06±5.5E+06	1.1E+04±1.3E+04	2.4				4.3E+05±3.2E+07	2.3E+03±3.2E+04	2.3	46.4±12.4	0.1±0.1	99.8	Tyagi *et al.* (2010)	
Jajmau I, Kanpur, India	UASB	1.3E+09±1.8E+09	3.3E+07±3.4E+07	1.6	9.3E+07±1.0E+08	3.9E+06±4.4E+06	1.4										NRCD (2010)	
Jajmau II, Kanpur, India	UASB	4.3E+09±2.2E+09	8.0E+08±2.0E+09	0.7	9.0E+08±9.4E+08	6.3E+07±9.2E+07	1.2										NRCD (2010)	
Mirjapur, India	UASB	8.2E+07±1.2E+08	3.7E+06±4.0E+06	1.3	2.4E+07±4.7E+07	1.9E+06±2.6E+06	1.1										NRCD (2010)	
Vadodara, Gujarat, India	UASB	8.0E+12	5.0E+07	5.2	3.0E+12	1.9E+07	5.2										Mungray and Patel (2011)	
Vadodara, Gujarat, India	UASB+ASP	8.0E+12	5.2E+05	7.0	3.0E+12	3.7E+05	7.0										Mungray and Patel (2011)	
Surat, Gujarat, India	UASB	2.7E+12	1.9E+07	5.2	1.0E+10	6.8E+06	3.2										Mungray and Patel (2011)	
Surat, Gujarat, India	UASB+ASP	2.7E+12	6.7E+05	6.7	1.0E+10	2.2E+05	4.7										Mungray and Patel (2011)	

TC: Total coliform; FC: Fecal coliform; FS: Fecal streptococcus; I: Influent; E: Effluent; Log R: Log removal; %R: Percent removal

Table A2.4: Pathogen Removal Potential of Sewage Treatment Plants (STPs) based on Waste Stabilization Pond and Its Variants

Location	Treatment Variation	TC (MPN/100 ml)			FC (MPN/100 ml)			*E. coli* (MPN/100 ml)			FS (MPN/100 ml)			Helminths Egg (No./L)			Reference	Remarks, if any
		I	E	Log R	I	E	Log R	I	E	Log R	I	E	Log R	I	E	%R		
Ixtapan de la Sal, Mexico	WSP	1.1E+03±1.1E+03	9.0E+00±9.0E+00	2.0	1.4E+02±1.5E+02	4.0E+00±2.0E+00	1.5				1.1E+03±1.1E+03	2.0E+00±1.0E+00	2.7				Alcocer *et al.* (1993)	
Rabat, Morocco	WSP	2.4E+08	2.0E+07	1.1	2.1E+07	4.6E+03	3.7				2.2E+07	2.3E+04	3.0			99.3	El-Hamouri *et al.* (1994)	
Melbourne, Australia	WSP							1.2E+07	8.0E+01	5.2							Hodgson and Paspaliasis (1996)	
Burwarton Estate, Shropshire, UK	WSP				1.1E+07	1.2E+02	5.0										Mara *et al.* (1998)	
Murviel les Montpellier, France*	WSP				3.6E+06	2.7E+04	2.1										Brissaud *et al.* (2000)	*FC in CFU/100 ml
Akuse, Ghana	WSP	8.0E+05-1.1E+07	0-2.7E+04	4.0	2.0E+04-1.0E+07	0-9.0E+01	4.0										Hodgson (2000)	
Catacamas, Honduras	WSP				1.8E+07	4.2E+05	1.6										Oakley *et al.* (2000)	
Tela, Honduras	WSP				1.2E+06	7.6E+03	2.2										Oakley *et al.* (2000)	
Masaya, Nicaraguya	WSP				1.5E+08	3.2E+06	1.7										Oakley *et al.* (2000)	
Granada, Nicaraguya	WSP				6.1E+07	4.6E+05	2.1										Oakley *et al.* (2000)	
Benslimane, Morocco	WSP	5.2E+08	8.0E+01	6.7	3.0E+06	3.0E+01	5.0				1.8E+06	5.0E+01	4.6	23	0	100	Kouraa *et al.* (2002)	
Pahari, Patna, India	AL	2.4E+08	9.0E+05	2.4	9.0E+07	5.0E+05	2.3										CPCB (2005)	
Karnal, India	OP	1.3E+07	1.1E+06	1.1	8.0E+06	8.0E+05	1.0										CPCB (2005)	
Sultanpur Lodhi, Punjab, India	OP	5.0E+07	4.0E+06	1.1	2.4E+07	9.0E+05	1.4										CPCB (2005)	
Phillore, Punjab, India	OP	9.0E+07	1.5E+07	0.8	9.0E+07	8.0E+06	1.1										CPCB (2005)	
Akosombo, Ghana	WSP	2.3E+05-3.8E+07	2.9E+02-1.8E+05	2.2	1.9E+04-1.7E+07	4.0E+01-9.0E+02	4.0										Hodgson (2007)	
Albireh, Israel	WSP				2.1E+07	2.6E+04	2.4				2.1E+06	6.5E+04	1.2				Al-Sa`ed *et al.*(2007)	
Sfax, Tunisia*	AL	1.4E+04-5.0E+07	2.0E+03-9.0E+05	1.7	4.3E+03-2.5E+07	1.0E+03-8.0E+05	1.4				1.7E+03-3.5E+06	1.3E+03-4.5E+05	1.2	15.5±1.6	7.4±1.0	52.2	Ellouze *et al.* (2009)	*TC and FC in CFU/100 ml
Malelane, South Africa*	WSP	2.5E+06	5.4E+05	0.7	1.8E+05	1.8E+04	1.0										Samie *et al.* (2009)	*TC and FC in CFU/100 ml
Rishikesh, Uttarakhand, India	WSP	2.3E+07±1.5E+08	1.1E+05±7.2E+05	2.3	5.3E+06±3.8E+07	2.5E+04±3.5E+05	2.3				4.7E+05±2.2E+06	1.7E+03±9.6E+03	2.4	50.0±18.4	0.2±0.30	99.6	Tyagi *et al.* (2010)	
Timarpur, Delhi, India	OP				3.5E+05	1.2E+02	3.5				8.5E+05	7.2E+01	4.1				Jamwal and Mittal (2010)	
Farrukhabad, India	OP	3.9E+07±6.1E+07	1.0E+05±3.2E+05	2.6	2.5E+06±3.4E+06	6.8E+03±1.8E+04	2.6										NRCD (2010)	
Nakuru, Kenya	WSP				5.4E+07-1.6E+08	4.0E+01-9.0E+02	4.0										Ngari *et al.* (2011)	

TC: Total coliform; FC: Fecal coliform; FS: Fecal streptococcus; I: Influent; E: Effluent; Log R: Log removal; %R: Percent removal

Table A2.5: Pathogen Removal Potential of Sewage Treatment Plants (STPs) based on Sequencing Batch Reactor

Location	Treatment Variation	TC (MPN/100 ml)			FC (MPN/100 ml)			*E. coli* (MPN/100 ml)			FS (MPN/100 ml)			Helminths Egg (No./L)			Reference	Remarks, if any
		I	E	Log R	I	E	Log R	I	E	Log R	I	E	Log R	I	E	%R		
Jurong Town, Singapore	SBR (Pilot)	3.0E+07-16.0E+07	0.2E+06-3.0E+06	1.7-2.2	8.0E+06-1.6E+08	4.0E+04 - 3.0E+06	1.7-2.3										Ng *et al.* (1993)	
Santiago de Compostela, Spain*	SBR (Bench Scale)				3.7E+04-1.0E+05	4.0E+03-1.0E+05	0.1	3.7E+04-1.0E+05	3.0E+02-4.3E+04	0.2							Arrojo *et al.* (2005)	*FC and *E. coli* in CFU/100 ml
Santiago de Compostela, Spain*	SBR (Bench Scale)				1.2E+06-1.8E+06	4.0E+03-1.0E+04	2.3	1.0E+06-1.4E+06	2.0E+03-4.1E+03	2.6							Arrojo *et al.* (2005)	*FC and *E. coli* in CFU/100 ml
Beer-Sheva, Israel*	SBR (Pilot)	2.5E+07	8.0E+05	1.5	5.4E+06	2.4E+05	1.4										Brenner *et al.* (2000)	*TC and FC in CFU/100 ml
Delhi Gate, Delhi, India	BIOFOR				1.0E+07	4.7E+05	1.4				1.6E+07	5.4E+05	1.5				Jamwal and Mittal (2010)	
Sen Nursing Home, Delhi, India	BIOFOR				1.0E+07	5.2E+05	1.3				9.8E+06	9.3E+05	1.0				Jamwal and Mittal (2010)	

TC: Total coliform; FC: Fecal coliform; FS: Fecal streptococcus; I: Influent; E: Effluent; Log R: Log removal; %R: Percent removal

Table A2.5: Pathogen Removal Potential of Sewage Treatment Plants (STPs) based on Membrane Bioreactor

Location	Treatment Variation	TC (MPN/100 ml)			FC (MPN/100 ml)			*E. coli* (MPN/100 ml)			FS (MPN/100 ml)			Helminths Egg (No./L)			Reference	Remarks, if any
		I	E	Log R	I	E	Log R	I	E	Log R	I	E	Log R	I	E	%R		
Indio, California, USA*	MBR (Pilot)	5.6E+07	2.0E+01	6.4													Côté *et al.* (1997)	*TC in CFU/100 ml
Maisons-Laffitte, France*	MBR (Pilot)	5.9E+07	4.3E+01	6.1													Côté *et al.* (1997)	*TC in CFU/100 ml
Tsukuba, Ibaraki, Japan	MBR (Pilot)				4.8E+07±6.9E+07	6.0E+00±3.8E+00	6.0										Ueda and Hata (1999)	
Owlwood, Leeds, UK*	MBR (Bench-scale)				8.8E+06-1.2E+07	<3.0E+00	6.9				5.2E+05-7.7E+05	<2.0E+00	>5.8				Ueda and Horan (2000)	*FC and FS in CFU/100 ml
Hammarby Sjostad, Stockholm, Sweden	MBR (Pilot)							-	-	5.0±0.9							Ottoson *et al.* (2006)	
Technion, Haifa, Israel*	MBR (Pilot)				3.4E+05±4.2E+05	2.7E+01±5.6E+01	4.1										Friedler *et al.* (2006)	*FC in CFU/100 ml
Guelph, Ontario, Canada*	MBR (Pilot)	2.5E+07	2.5E+02	5.0	9.6E+06	<2.0E+00	-										Zhang and Farahbakhsh (2007)	*TC and FC in CFU/100 ml
Sfax, Tunisia*	MBR (Pilot)	3.7E+04±9.0E+03	<2.0E+00	-	2.1E+04±5.0E+03	<2.0E+00	-				3.5E+04±8.0E+03	<2.0E+00	-	15±4	0	100	Saddoud *et al.* (2007)	*TC, FC and FS in CFU/100 ml
Daejeon, Korea*	MBR (Pilot)	-	1.1E+01	-	-	5.0E+00	-	-	2.0E+00	-							Chae *et al.* (2007)	*TC, FC and *E. coli* in CFU/100 ml
METU, Inönu Bulvari, Ankara, Turkey	MBR (Pilot)	-	1.4E+02-3.50E+02	5.0-6.0	-	<2.0E+00-1.8E+01	7.0										Komesli *et al.* (2007)	
Rabat, Morocco	MBR (Bench-scale)				1.4E+05±1.1E+05	6.8E+01±1.2E+02	2.0										Merz *et al.* (2007)	
Bradford, London, UK*	MBR (Pilot)	2.5E+05±6.3E+00	4.0E+00±1.0E+01	4.7				6.3E+03±1.2E+01	6.3E+02±6.3E+00	1.0							Winward *et al.* (2008)	*TC and *E. coli* in CFU/100 ml
Castle Hill, Sydney, Australia*	MBR (Bench-scale)	2.7E+04	4.3E+03±2.4E+03	0.8													Guo *et al.* (2008)	*TC in CFU/100 ml
Sfax, Tunisia*	MBR (Pilot)	2.1E+04-5.0E+07	<2.0E+00	-	9.0E+03-3.0E+07	<2.0E+00	-				3.5E+03-3.0E+06	<2.0E+00	-				Ellouze *et al.* (2009)	*TC and FC in CFU/100 ml
Verona, Italy	MBR (Pilot)	1.0E+06-9.2E+07	7.0E+01-2.0E+02	4.7-5.1				Present	Absent	NC							Bolzonella *et al.* (2010)	
Bologna, Italy*	MBR	7.9E+06-2.0E+08	2.6E+01-3.1E+03	4.8-5.5	2.1E+06-1.7E+08	1.0E+00-1.3E+01	6.0-6.3	1.4E+06-7.9E+07	1.0E+00 - 4.0E+00	6.2-7.0							Zanetti *et al.* (2010)	*TC and FC in CFU/100 ml
Seoul, Korea*	MBR (Bench-scale)				1.2E+03	7.0E+02	0.2	4.0E+03	1.3E+03	0.5							Jong *et al.* (2010)	*FC and *E. coli* in CFU/100 ml
San Diego, California, USA*	MPR (Pilot)	1.0E+05-2.0E+08	<1.0E+01	5.8-6.9	4.0E+05-4.3E+07	<1.0E+01	5.5-6.0										Hirani *et al.* (2010)	*TC and FC in CFU/100 ml
Sydney, Australia	MBR							-	-	5.4-6.7							Pettigrew *et al.* (2010)	
Castell d'Aro, Catalonia, Spain	MBR (Pilot)							1.0E+06	<2.0E+00	5.1							Marti *et al.* (2011)	**E. coli* in CFU/100 ml
Garching, Germany	MBR (Pilot)				4.3E+06	4.9E+01	5.0										Martinez-Sosa *et al.* (2011)	
UNAM, Mexico	MBR (Pilot)				3.6E+06-4.7E+06	<2.0E+00	-							10±2	<1	99	Herrera-Robledo *et al.* (2011)	
Riyadh, Saudi Arabia*	MBR (Pilot)				1.5E+07	2.0E+03	3.9										Zahid and El-Shafai (2011)	*FC in CFU/100 ml

TC: Total coliform; FC: Fecal coliform; FS: Fecal streptococcus; I: Influent; E: Effluent; Log R: Log removal; %R: Percent removal